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ENGINEERING AND SERVICES
LABORATORY TECHNICAL REPORT
(ESL TR) 80-34

THE U.S. AIR FORCE ACADEMY SOLAR ENERGY RESEARCH PROJECT FINAL INTERIM REPORT

JULY 1980

AIR FORCE ENGINEERING
AND SERVICES CENTER
(Tyndall Air Force Base
Florida 32403)

PREFACE

This report was prepared within the Department of Civil Engineering, Dean of Faculty (DFCE), United States Air Force Academy for the Air Force Engineering and Services Center (AFESC) under work unit 2054 5005. This work was accomplished during the period May 1978 to January 1980. Prior to 15 March 1979, this work was accomplished for the Civil and Environmental Engineering Development Office (CEEDO) which became the Engineering and Services Laboratory of the Air Force Engineering and Services Center.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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This report presents the solar energy research that was conducted by the Air Force Academy from May 1978 to January 1980. This research continued to gather operational performance data and maintenance experience on a retrofit residential solar space heating system. Data analysis includes comparison to prior years' results. Separate chapters are devoted to analyzing the performance of evacuated tube collectors and the home's reaction to sole dependency on solar energy during a selected winter period. Considerable

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attention is given to actions that were taken to prepare the system for a return to normal occupancy (the home was vacant until October 1979). Information concerning the perceived need for development of an operations and maintenance manual and a "homeowner's" manual is included. Complete copies of the developed manuals are appendices to this report.

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FINAL INTERIM TECHNICAL REPORT ON USAFA SOLAR TEST HOUSE

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ESL Technical Report 80-34
July 1980

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FOREWORD

This report discusses work conducted by the Department of Civil Engineering, U.S. Air Force Academy, Colorado, under Project Order DTC-9-32 issued by Detachment 1, ADTC/PRF at Tyndall AFB, FL 32403. Although funding stopped on 30 September 1979, project work continued until January 1980.

All project investigators helped author this report. The Project Director was Colonel Wallace E. Fluhr, Professor and Head of the Department of Civil Engineering.

The authors are indebted to many people. Particular thanks go to personnel of the 7625th Civil Engineering Squadron who accomplished the major work of changing collector systems on the ground array in September of 1978 and 1979. Mr. Jack Whelton and Sgt Bobby Sanders also helped to insure that these modifications were accomplished correctly and on schedule.

We are also grateful to Captain Dennis R. Topper and Captain Ralph C. Rhye for valuable assistance in the preparation of this manuscript. Last, but by no means least, we wish to sincerely thank Mrs. Carmen Villines and Mrs. Penny Grayson for their dedicated efforts in typing the report. Mrs. Grayson's editorial assistance was particularly noteworthy; she is a true professional in every sense of the word.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This report is the fourth and final in a series of interim reports which describe the performance of the USAFA Solar Test House. This report covers work done from May 1978 to January 1980. The data which summarizes the home's performance terminates in April 1979. The cessation of data gathering was made necessary by the removal of the research instrumentation and control system and installation/testing of the mini-microprocessor controller (reference Chapter 5).

This report increases the knowledge base established by the first three interim reports (1, 2, 3). Emphasis in this report is given to evaluation of evacuated tube collectors and measures taken to convert the home from a research laboratory to a normally occupied military family housing unit.

1.2 Objectives

The objectives of the research during this period were:

a. Install and monitor the performance of evacuated tube collectors on the ground array.

b. Determine the environment which would exist in the home if it was solely dependent on the solar system for energy.

c. Continue to monitor the system's performance with regard to previously implemented operational changes and maintenance considerations.

d. Install and test a locally designed and fabricated mini-microprocessor system controller.

e. Prepare the home for termination of the research project and return to normal occupancy.

1.3 Contents of the Report

Data is presented and analyzed from May 1978 to April 1979. This analysis includes discussion of the system's performance compared to prior year results. Separate chapters are devoted to analyzing the performance of evacuated tube collectors and the home's reaction to sole dependency on solar energy during a selected winter period.

Considerable attention is given to actions that were taken to prepare the system for return to normal occupancy. An accounting of the efforts which were made to insure the solar system was as maintenance free and dependable as possible is presented.

A chapter concerning the perceived need for development of an operations and maintenance manual and a "homeowner's" manual is included. Complete copies of these manuals are included as appendices to this report.

Finally, brief conclusions reached during this period of operational research are listed for easy reference.

Scientific International (S.I.) units are primarily used but are generally followed by parenthetic English equivalents. Some data is presented in mixed or pure English units if it is thought clarity will be gained.

CHAPTER 2

FINAL YEAR DATA ANALYSIS AND RESULTS

2.1 Introduction

This chapter presents and discusses the performance data from May 1978 to April 1979. The tabularized data for this period constitutes Appendix A of this report. Collector performance is covered but detailed comparison of the evacuated tube collectors to the flat plate system is reserved for Chapter 3. Comparison of the total system's performance to previous years can be found in this project's summary report (4). Since the home was unoccupied, a section is devoted to comparing the energy demand of the structure in this status to when it was occupied. Also included are results of an investigation on the safety of urea formaldehyde (UF) foam insulation.

2.2 Collector Performance

As forecasted by the last interim report (3), evacuated tube collectors were installed on the ground array in September 1978. Twelve General Electric TC-100 collectors with a total area of 17.8m^2 (192 ft^2) were installed. The total area of the previously installed flat plate collectors was 25.4m^2 (273 SF). The evacuated tube collectors began operation in October 1978 and remained installed until September 1979. The roof array configuration continued to be 25.4 m^2 (273 ft^2) of flat plate collectors. Both arrays were inclined at a 52^o angle from horizontal.

The total amount of solar energy available to the collectors for the record period is shown on Figure 2-1. Figure 2-2 shows the instantaneous efficiency achieved by both collector arrays. You will note that the ground array consistently out-performed the roof array during the time

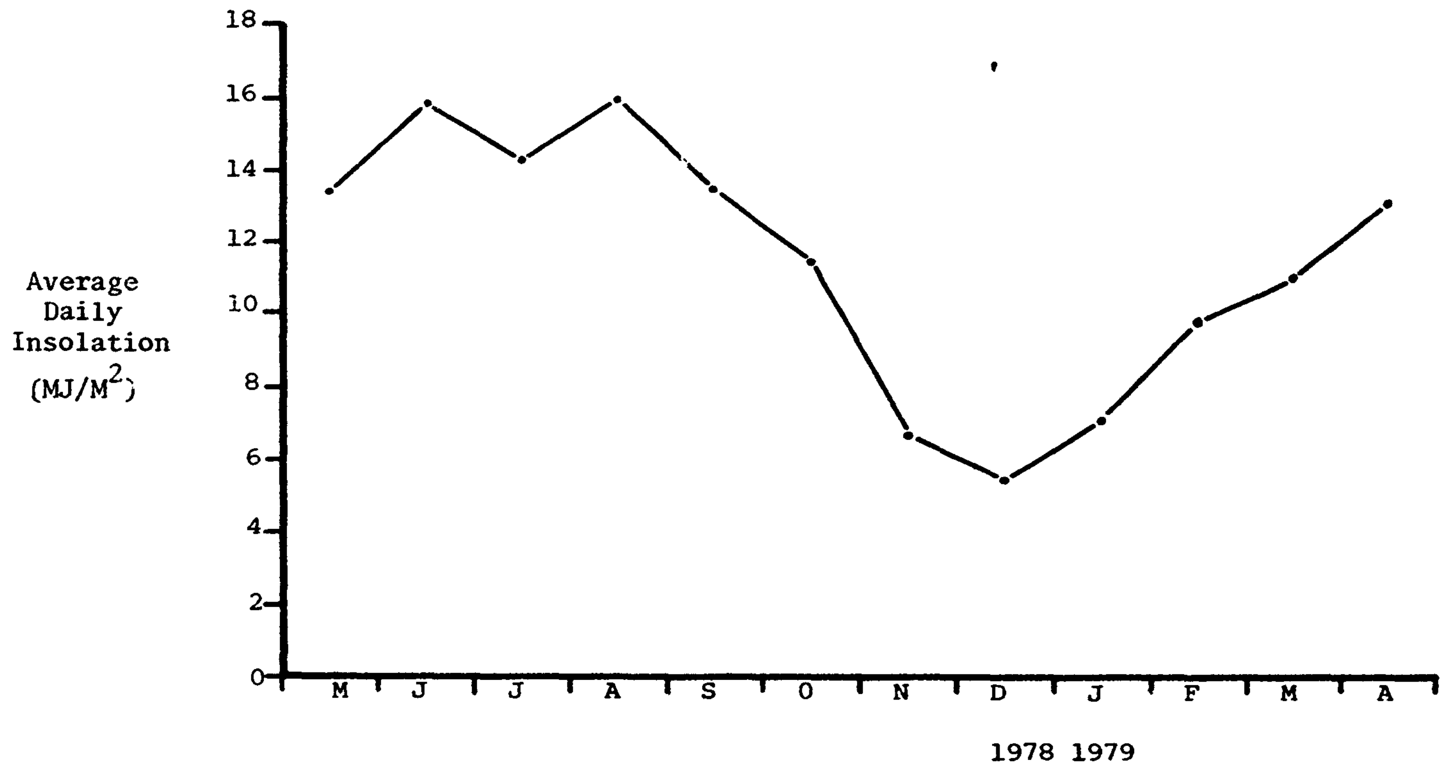


Figure 2-1. Monthly Energy Available (Horizontal)

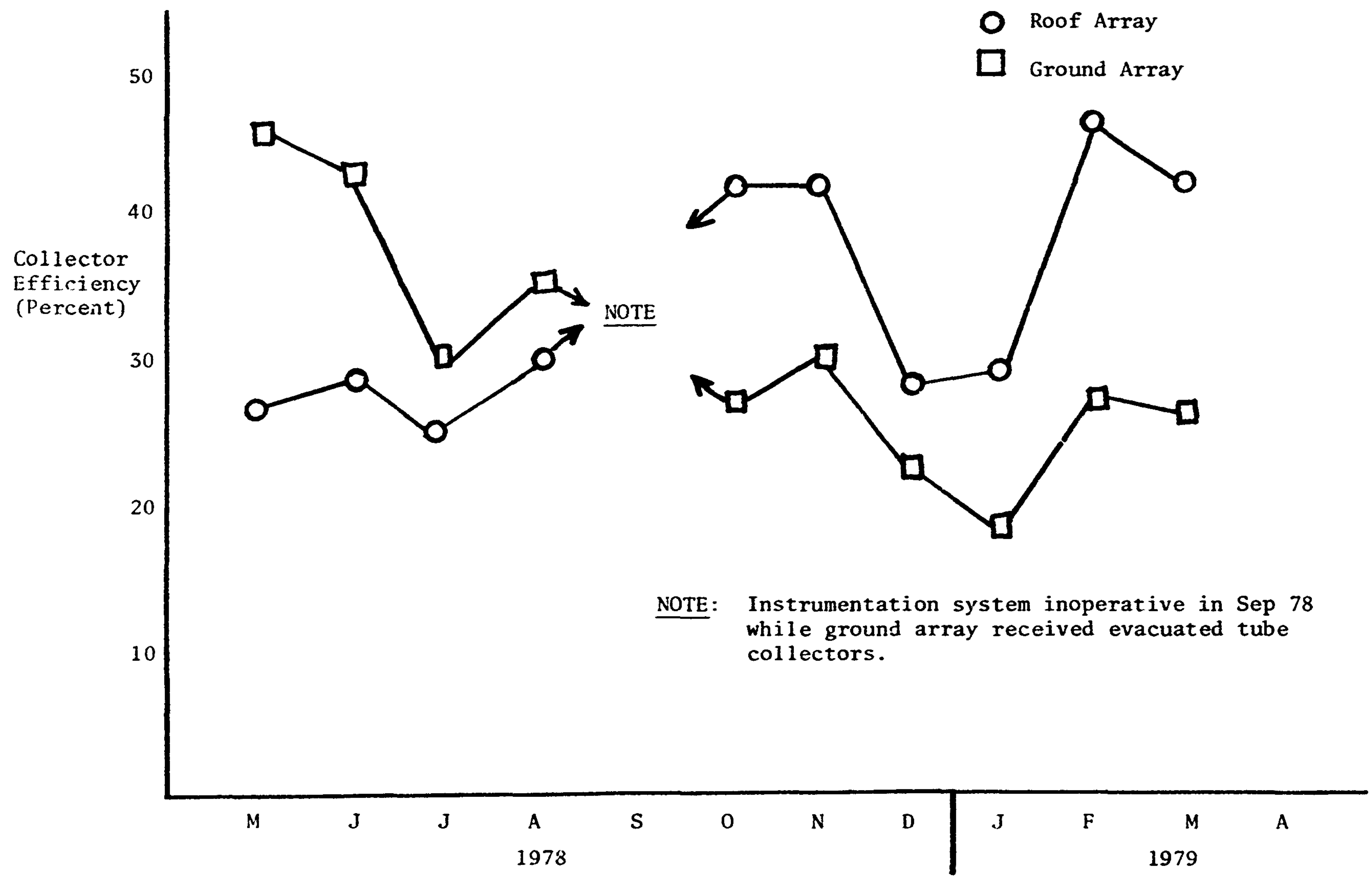


Figure 2-2. Ground and Roof Array Collector Efficiency

that both arrays possessed flat plate collectors. This coincides with past years' results. This situation changed dramatically when the ground array received the evacuated tube collectors. The flat plate roof array achieved better performance than the evacuated tube collectors for this application and location. Detailed discussion of this result is in Chapter 3.

The increased collection efficiency for both arrays in February 1979 needs further explanation. During the last 18 days of this month an experiment which we called the Loss of Energy Situation Simulation (LESS) was conducted. The auxiliary energy was shut off and the home was solely dependent on the solar system for heat. In effect, the interior temperature of the home was allowed to "float". This experiment resulted in the drawdown of the storage tank temperatures, and in turn, of the collector fluid temperatures. Since the collectors could run cooler, their efficiency improved as shown. It is theorized that the flat plate roof array's efficiency improved more than the evacuated tube collectors due to the tubes' greater resistance to thermal loss and insensitivity to working fluid temperature changes. The LESS experiment is discussed in detail in Chapter 4.

The overall efficiency of the flat plate system from May-August 1978 was 33.1 percent - with 23.264 GJ (22.1×10^6 Btu) collected from 70.286 GJ (66.7×10^6 Btu) available. The efficiency of the evacuated tube collectors (October 78-March 79) was 25 percent with 13.6 GJ (12.5×10^6 Btu) collected from 52.688 GJ (50×10^6 Btu) available. The flat plate roof array efficiency during the same period was 38.3 percent with 23.938 GJ (22.7×10^6 Btu) collected out of 62.494 GJ (59.3×10^6 Btu) available.

The overall efficiency of the combined collector systems during October 1978 to March 1979 was 32.2 percent. The flat plate collectors on the roof array contributed 64.5 percent of the total collected energy; they represented 58 percent of the installed collector area. The flat plate collectors were operated at a working fluid flow rate of .015 m^3/min (4 GPM). This represents a rate of .0006 m^3/min per square meter of area (.015 GPM/ft^2); the researchers believe this rate to be optimum for this installation (3). The evacuated tube collectors were operated at .009 m^3/min (2.4 GPM). This is a rate of 5×10^{-4} m^3/min per square meter of collector area (.013 GPM/ft^2) which is within the manufacturer's recommendations. It is believed that the previously mentioned LESS experiment did not greatly affect the overall efficiency results discussed above.

2.3 System Performance

The solar system continued to perform well during the last winter of the research work. Figure 2-3 shows the monthly degree days and the corresponding energy demand of the home. The demand and degree day plots correspond extremely well. Prior years' data, although generally correponding, never exhibited this high degree of correlation. Typically, January was the coldest month and produced the highest energy demand.

Figure 2-4 displays the total energy demand and the fraction contributed by the solar energy system. When viewed with Figure 2-1 it shows that the solar system contributed a sizable amount of energy to the home even when solar availability is at a minimum. The lowest solar fraction was reached in December when the solar system provided only 27 percent of the total demand. The reader is once again reminded of the LESS experiment (see Chapter 4) conducted in February. This experiment resulted in an artificially high solar fraction for this month.

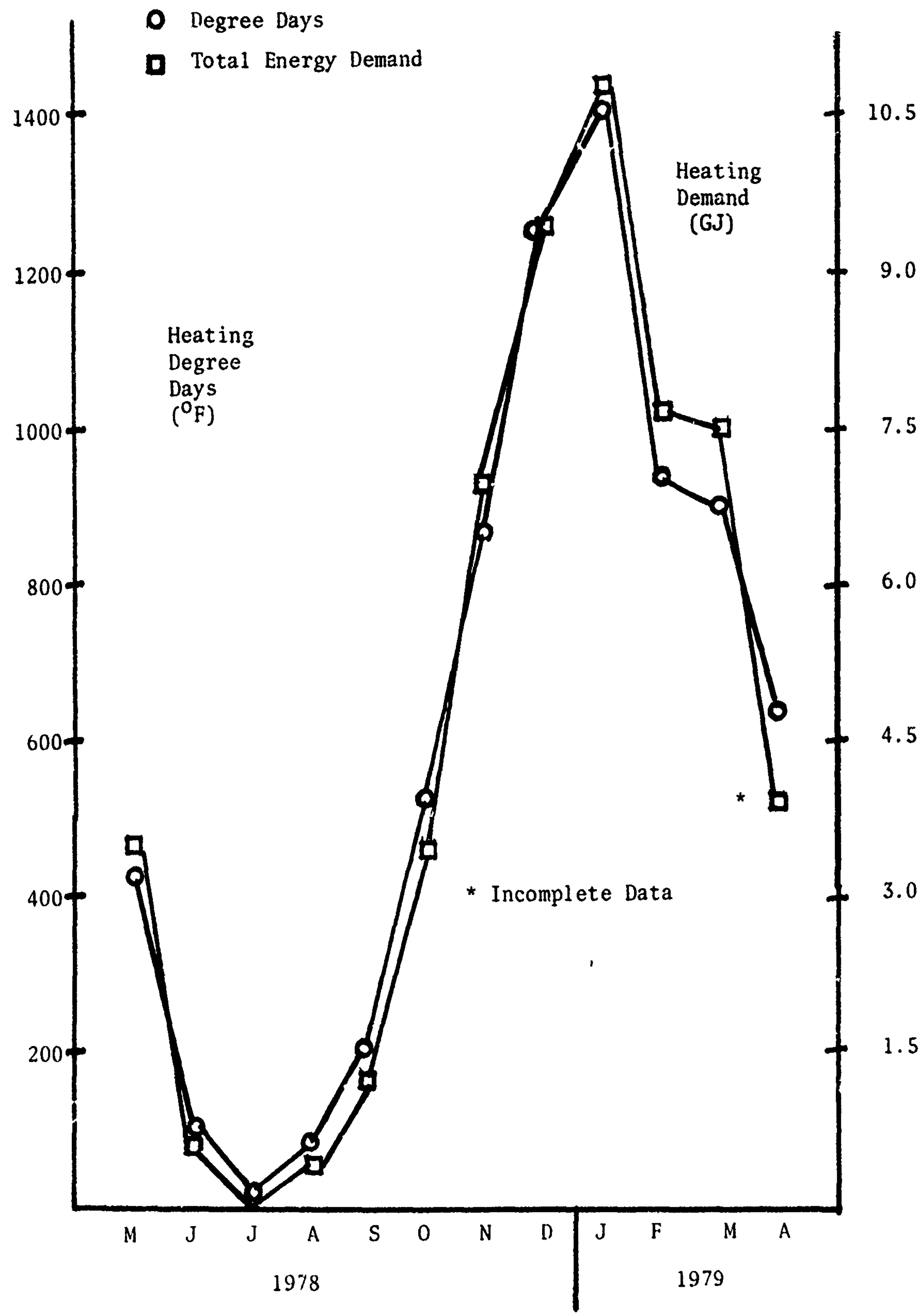


Figure 2-3. Monthly Degree Days and House Heating Demand

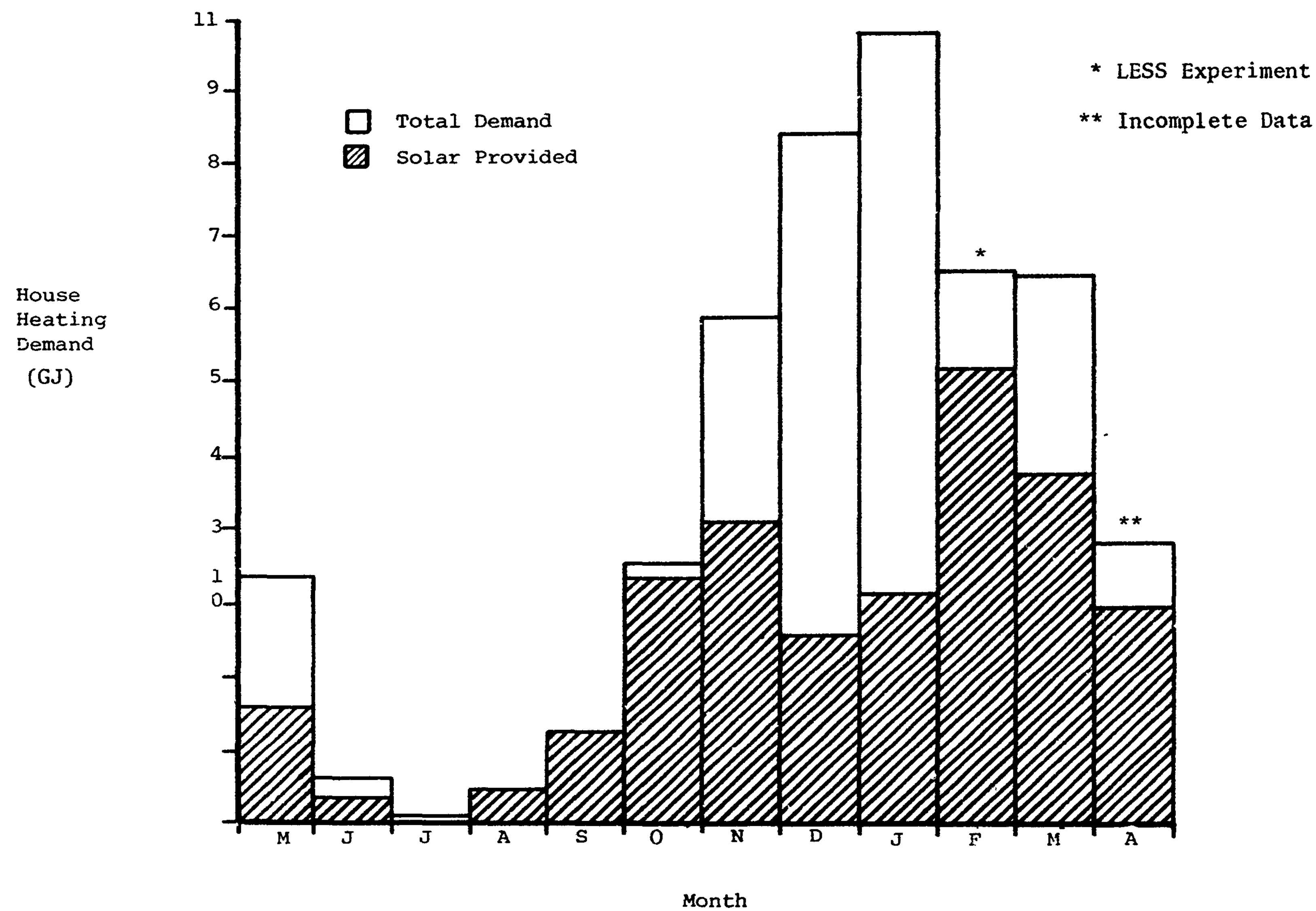


Figure 2-4. Monthly House Heating Demand and Solar Fraction

The monthly solar fractions are shown in Figure 2-5. The unusually low solar contributions in May and June of 1978 were due to unseasonable spring snowstorms combined with operational problems of the system. They were nonetheless low-demand months and consequently did not greatly affect the annual performance. The exact figures on the monthly performance are given in Table 2-1. The total annual solar contribution of 55.4 percent is less than the 61.8 percent reported for the corresponding period in the last interim report (3). This decrease in performance is attributable to three factors:

a. This year's weather was more severe. The home's energy demand increased by nearly 4½ percent when compared to May 1977 through April 1978.

b. The system's collector area was reduced from 50.8m^2 (546 ft^2) to 43.2 m^2 (465 ft^2) as of October 1978. This 15 percent reduction was due to the installation of the evacuated tube collectors on the ground array. Collector area is the primary parameter which influences the solar fraction.

c. The evacuated tube collectors also operated at lower efficiencies than the flat plates (ref Section 2.3 and Chapter 3).

As a result of the latter two items, the total amount of solar energy provided to the home was 6½ percent less in 78-79 than in 77-78 (30.57 GJ vs 32.676 GJ). It must be pointed out, however, that the available solar insolation also decreased approximately 8 percent during the high-load months of October through April. (64 MJ/m^2-day in 78-79 vs 69.6 MJ/m^2-day in 77-78). The LESS experiment in February affected these cumulative results somewhat but not greatly.

Table 2-1

House Energy Demand and Solar Fraction

Month	Demand (GJ)	Solar (GJ)	% Solar
May 1978	3.38	1.59	47
June 1978	.63	.35	56
July 1978	--	--	--
August 1978	.45	.45	100
September 1978	1.23	1.23	100
October 1978	3.55	3.34	94
November 1978	6.91	4.08	59
December 1978	9.39	2.55	27
January 1979	10.77	3.11	29
*February 1979	7.51	6.19	82*
March 1979	7.49	4.75	63
**April 1979	3.83	2.93	76
Annual	55.14	30.57	55.4%

* LESS Experiment

** Partial Data

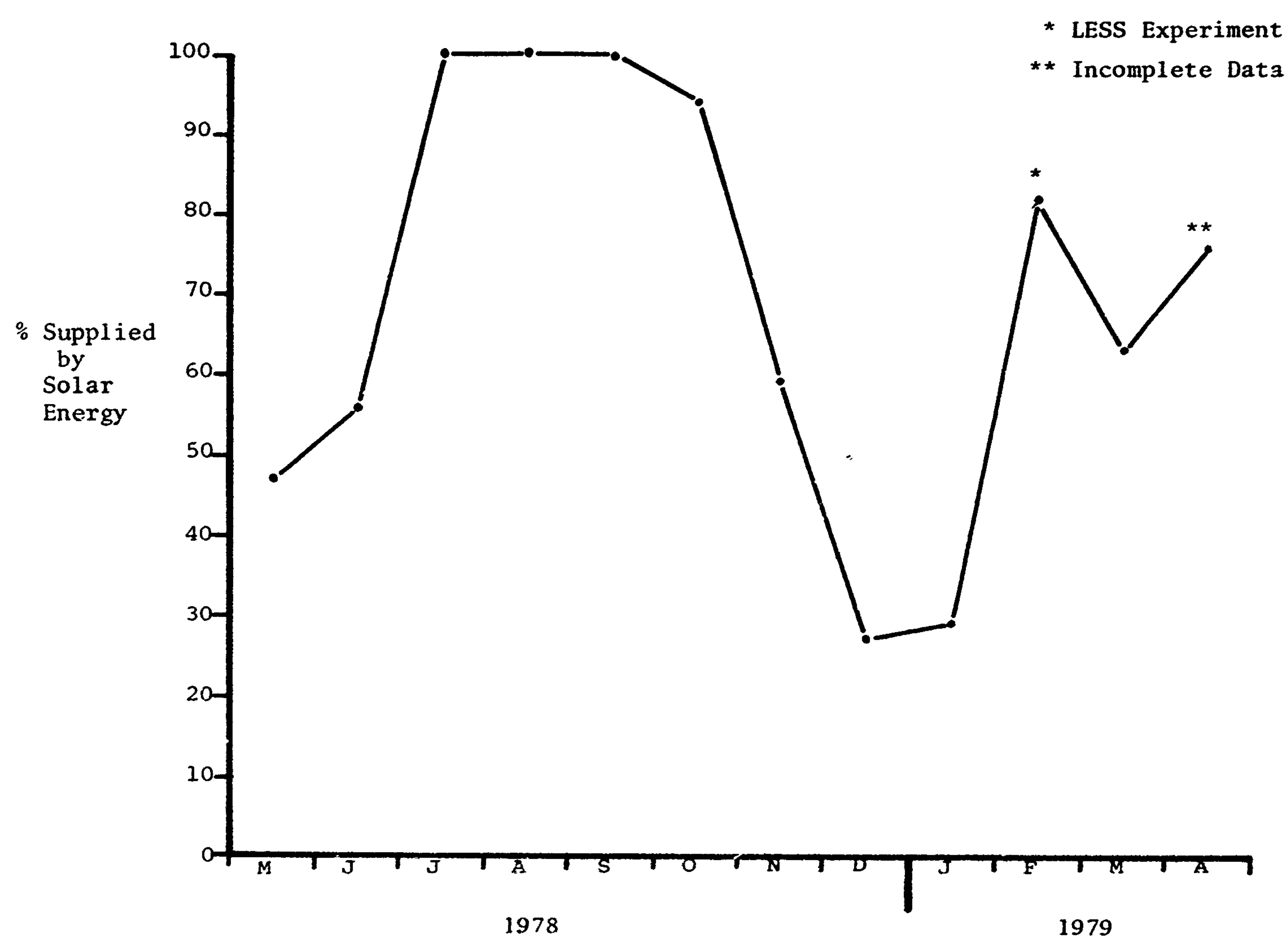


Figure 2-5. Monthly Solar Contribution

The overall thermal performance of the solar system during the heating season is presented in Table 2-2. This performance compares relatively well to the previous winter, though it is lower in all categories. The reasons for this performance decrease have been previously discussed. The reader is referred to this project's summary report (4) for a comparison of all years of operation.

Table 2-2

Solar System Thermal Performance, Oct 78 - Mar 79
(Partial Data from Apr 79 not Included)

Thermal Parameter	%
$\frac{\text{Solar Energy Collected \& Stored}}{\text{Solar Energy Available to Collectors}}$	32
$\frac{\text{Solar Energy Provided to House}}{\text{Solar Energy Stored}}$	65
$\frac{\text{Solar Energy Provided to House}}{\text{Total House Energy Demand}}$	53
$\frac{\text{Solar Energy Provided to House}}{\text{Solar Energy Available to Collectors}}$	21

2.4 Influence of Occupancy on Energy Consumption

The last interim technical report (3) proposed that the energy demand to degree day ratio increased when the home became unoccupied in January 1978. Since that report only analyzed three months of data, it was decided to investigate this apparent result more closely during the final reporting period.

It has already been pointed out in Figure 2-3 that the energy demand of the home closely paralleled the degree days. It is proposed that a vacant home, which does not have a significant amount of internal

thermal mass, responds more quickly and closely to environmental conditions. In addition, the internal heat gains associated with occupancy (appliances, people, lights, etc.), which were never measured in this project, would tend to inhibit the close correlation which this figure displays. Since the home is extremely well insulated, however, daily "degree day and demand" plots do not track nearly as well as the monthly summaries.

Table 2-3 compares the energy demand of the home versus the degree days for high consumption months before and after the home was vacated. (This table is presented in English units since it is believed that this ratio is widely used by Air Force engineers.) These data indicate that the energy demand of the unoccupied home was approximately 14 percent greater than when it was occupied. It may also be noteworthy to mention that all window blinds remained closed during the time the home was unoccupied. This prevented solar energy gains in the winter which would have tended to reduce the measured energy consumption of the structure.

The conclusion that an empty dwelling requires more energy from typical heating sources than do occupied buildings may be more important than is immediately apparent. Solar performance is often reported in terms of the solar fraction and this is directly dependent on the total energy demand of the structure. Consequently, the solar performance reported by research projects in which the structure is unoccupied may be conservative. In summary, the energy input to an occupied residential structure for nonheating purposes (e.g., cooking gas, normal electricity consumption) seems to have a significant bearing on the traditional space heating energy demands.

Table 2-3

Effects of Occupancy on Energy Demand

HOUSE OCCUPIED			HOUSE UNOCCUPIED		
TIME	DD(^{o}F)	DEMAND (10^{6}BTU)	TIME	DD(^{o}F)	DEMAND (10^{6}BTU)
Feb 77	723	7.34	Feb 78	1002	8.90
Mar 77	986	6.53	Mar 78	801	7.78
Apr 77	603	2.87	Apr 78	582	6.51
Oct 77	546	3.60	Oct 78	528	3.37
Nov 77	846	6.53	Nov 78	869	6.55
Dec 77	950	7.24	Dec 78	1266	8.91
Total	4654	34.11	Total	5048	42.02
$\frac{\text{Demand}}{\text{DD}} = 7330 \frac{\text{BTU}}{\text{DD}}$			$\frac{\text{Demand}}{\text{DD}} = 8320 \frac{\text{BTU}}{\text{DD}}$		

2.5 Investigations on UF Foam Insulation

As reported in earlier work (2) the USAFA solar home received urea formaldehyde (UF) foam in the walls in February 1977. USAF directives prohibited the use of this type of insulation, but due to the closely controlled environment which existed in this research project a waiver to this policy was approved. The prohibition on using UF foam at that time centered on concerns regarding the effect of the high volume of water used to inject the foam. These fears proved to be unfounded. One section of a wall interior was inspected eight months after injection of the foam and no deterioration of the studding, wallboard or the original rock wool insulation was observed. In addition, no shrinkage or cracking of the foam was apparent. The dry climate which exists at this installation could have helped to achieve these positive results.

Since the UF foam was installed, the U.S. Consumer Product Safety Commission and others have reported that it can release formaldehyde gas into living areas. This gas is toxic and can cause respiratory problems, headaches and other health problems in humans. To investigate this potential problem, the Frank J. Seiler Research Laboratory was requested to determine if formaldehyde vapors could be detected in the home. On 18 January 1980 an air sampling device (approved by OSHA) was placed in the home. At least 336 liters of air were drawn through the sampler and the adsorbent material was subsequently checked for the presence of formaldehyde. The equipment used was capable of detecting the presence of vapor in the parts per million range; none was found. The use of UF foam insulation is believed to have been safe, to date, in this project. It is certainly an extremely effective insulative material but extreme caution must be exercised in any future installations due to the potential health problems.

CHAPTER 3

EVACUATED TUBE COLLECTOR PERFORMANCE

3.1 Introduction

As stated in the third interim technical report (3), evacuated tube collectors built by General Electric (GE Model TC-100) were installed on the ground array (Figure 3-1). Operation began and data gathering started in October 1978. This collector system research centered on operational problems associated with these advanced collectors and their interface with the existing retrofit solar system.

The researchers realized from the outset that evacuated tube collectors are mainly designed to supply very high temperature hot water to absorption chillers or for industrial purposes. Evacuated tube collector efficiency curves tend to be very flat. A lower temperature application therefore does not take advantage of this characteristic. Consequently, their use in a direct space heating system could force them to efficiencies which would be lower than flat plate collectors in the water temperature range used at the Solar Test House (STH) (see Figure 3-2). Also, flow rate control at the very low flow rates used by the TC-100 collectors is difficult. These factors, no doubt, hampered the performance of the evacuated tubes and the analysis of the data they produced.

3.2 Performance Data

Table 3-1 shows the results obtained from the experiment period and compares them against the Revere flat plate collectors as well as the previous year's data. This data reveals that the TC-100 collectors did perform at a lower efficiency than the flat plate collectors installed on the roof. For the six-month period given in the table, the evacuated tube

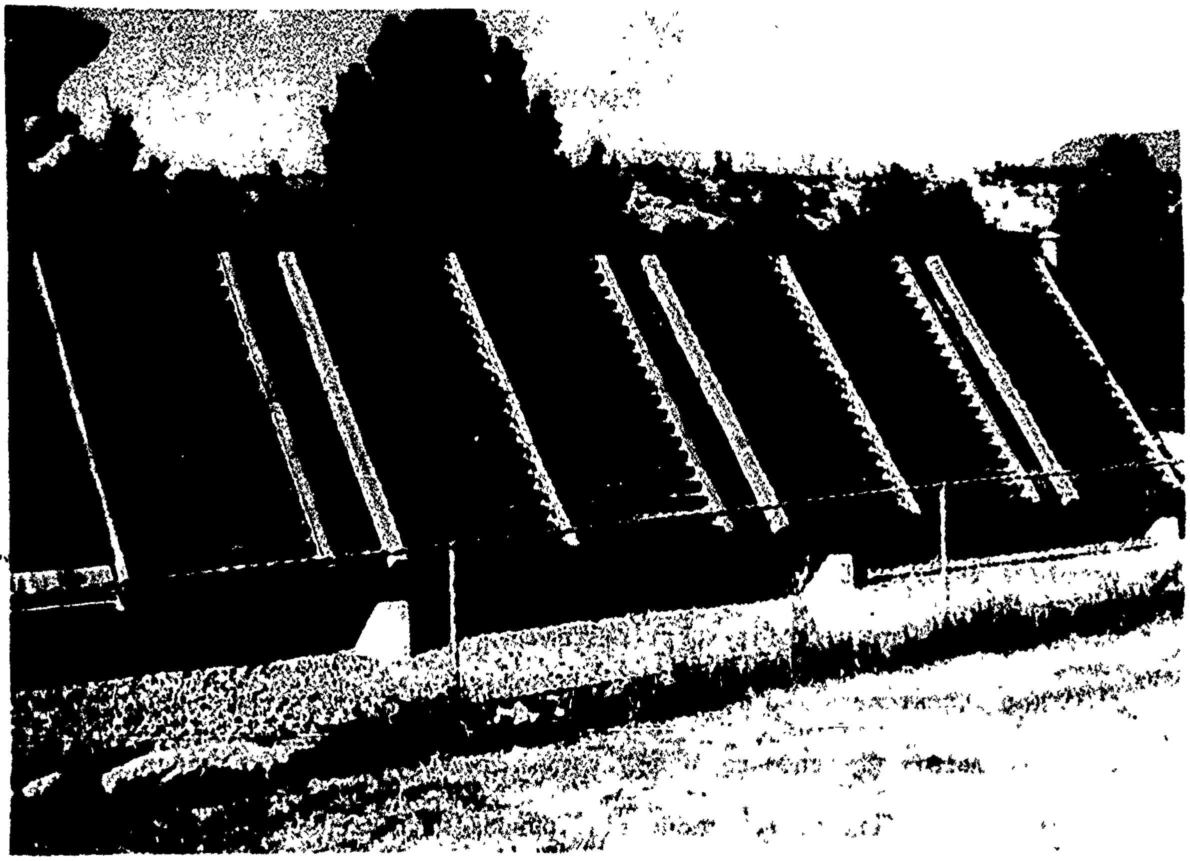


Figure 3-1. Evacuated Tube Collectors on Ground Array

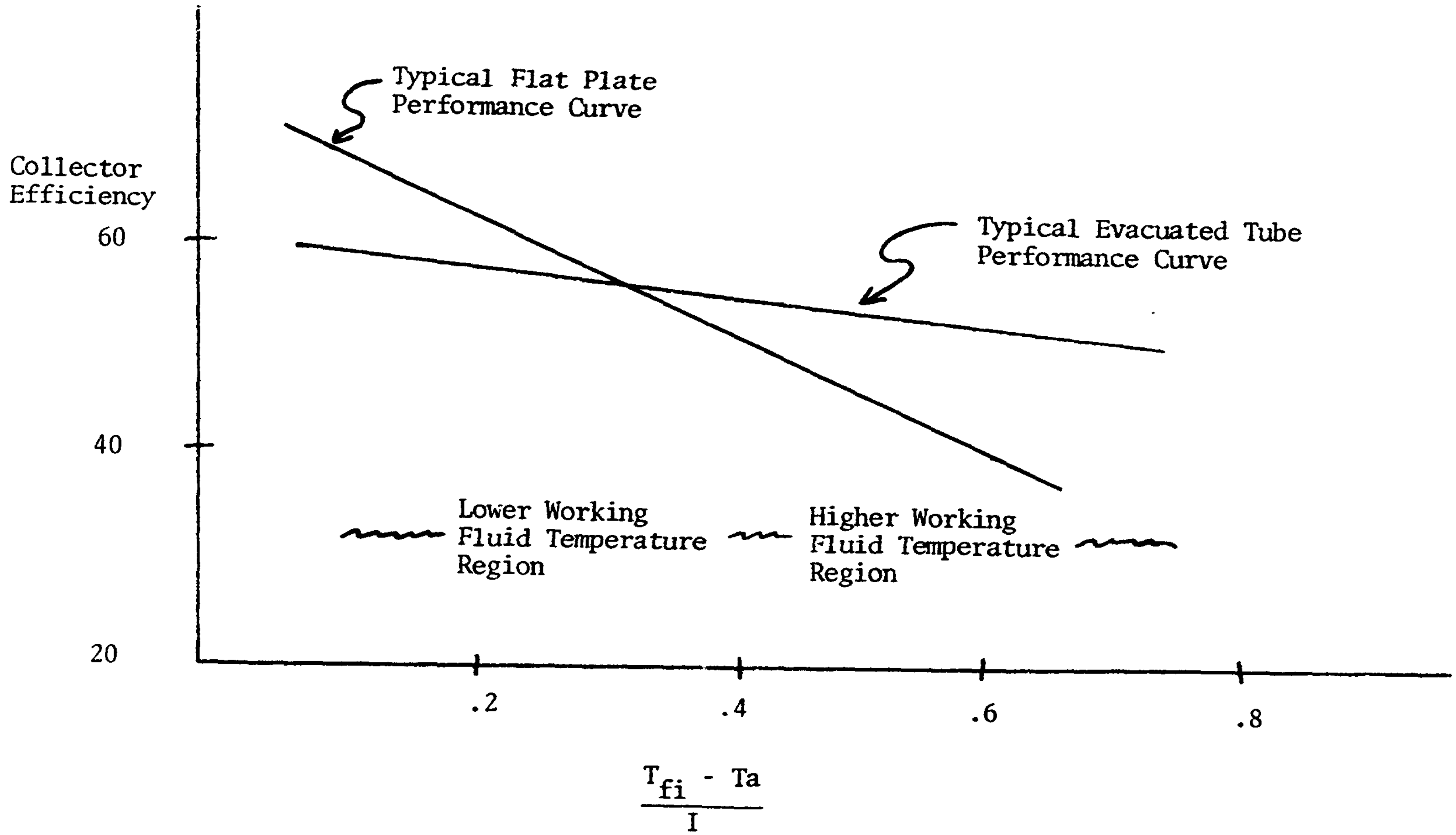


Figure 3-2. Typical Flat Plate and Evacuated Tube Collector Performance Curves

collectors' average instantaneous efficiency was only 25 percent. This is especially significant when compared to the roof array performance which shows an efficiency of 38 percent. Both the roof and ground arrays were positioned at 52° inclination during the entire test. The lower portion of Table 3-1 shows the data from the same months of the previous year for comparison. The ground array was more efficient than the roof array during the 77-78 heating year. This observation leads to the conclusion that the lower ground array efficiency in 78-79 was due to the evacuated tubes' lower efficiency and not just a result of some inherent system difference between the roof and ground array.

Also significant is the rise in efficiency of the roof array from 77-78 to 78-79. As can be expected, this system has always shown a direct correlation between collection efficiency and the inbound water temperature. Due to the decrease in the energy supplied by the ground array to the storage tank, the tank's temperature was lower in 78-79. This in turn led to lower temperature water being sent to the collectors and decreased the energy losses from the collectors. It is felt that this argument could explain the rise in efficiency of the roof array between years.

3.3 Observations

Other observations regarding the TC-100 collector operation follow.

Since the thermal mass of the evacuated tubes is much lower than the flat plate collectors, their thermal response is much more rapid. As a result, the TC-100 collectors would generally try to start up earlier than the flat plate collectors. However, the arrival of cold water from the underground supply pipe would cool them down rapidly and the system

Table 3-1

Evacuated Tube and Flat Plate
Performance Comparison

1978-1979 Heating Season

	Ground Array (TC-100 Evacuated Tubes)			Roof Array (Revere Flat Plates)		
	Available (MJ)	Collected (MJ)	%	Available (MJ)	Collected (MJ)	%
Oct 78	9491	2517	27	11490	4801	42
Nov 78	8197	2470	30	8635	3611	42
Dec 78	7508	1636	22	9089	2579	28
Jan 79	9946	1834	18	12040	3518	29
Feb 79	9438	2570	27	11425	5268	46
Mar 79	7070	1864	26	8559	3598	42
	51650	12891	25	61238	23375	38

Overall (32%)

1977-1978 Heating Season

	Ground Array (Flat Plates)			Roof Array (Flat Plates)		
Oct 77	6180	1765	29	6180	1580	26 1
Nov 77	11240	2854	25	11240	1855	17
Dec 77	8733	2450	28	8733	2324	27
Jan 78	9544	3204	34	8788	2730	31 2
Feb 78	9388	4230	45	9388	3417	36
Mar 78	10575	5344	51	10575	4671	44
	55660	19847	36	54904	16577	30

Overall (33%)

1 Partial Data - Pyranometer out until 12 Oct 77

2 RA sensors out two days

would shut down. About three cycles would be required before the evacuated tubes would stay hot enough to collect useful energy. Similarly, in the afternoon, the evacuated tube collectors would shut down first due to a lack of thermal mass from which to remove energy that had been stored during the day. This latter observation is contrary to commonly held beliefs (5).

This collector system requires great care in installation of the plumbing system. The original plumbing was installed using standard solder. The first time the collectors shut down during a sunny day, the pressures in the collectors rose so rapidly that many of the small tees and elbows failed. This occurred despite the presence of a pressure relief valve on the array. The repair work was accomplished using silver solder. Under subsequent stagnation conditions other solder connections failed but those previously repaired with silver solder remained intact. With respect to the evacuated tubes themselves, the problem of breakage existed when they overheated during stagnation conditions. Breaks for unknown reasons were also encountered during normal operation. It is theorized that material defects was the primary reason for these failures. After a shutdown for system repairs, cold water was purposely sent to the hot ground array and one tube broke because of the thermal shock caused by rapid cooling of the hot tubes. Almost all the tubes which broke due to thermal causes were the last tube in the sinnuous path out of a collector. This can perhaps be explained by the fact that these uppermost tubes saw the highest temperature water after it had passed through all the other tubes in a specific collector.

The evacuated tubes were installed with a reverse return plumbing system. The resultant flow balance was very good as evidenced by the

three parallel clusters performing very close to each other. The installed sensor system allowed measurement of each cluster's performance directly; this permitted the Lexan® cover removal experiment to be conducted.

3.4 Lexan® Cover Removal Experiment

The TC-100 collectors can be installed with covers for hail, snow, and vandalism protection. At the time of purchase either acrylic or Lexan® covers were available. Lexan® covers were purchased and used for this application. During the first months of operation, all 12 collectors had these covers in place. On the evening of 6 March 1979, the second cluster's covers were removed. The data of 22 February to 25 March is shown on Figure 3-3 and in Table 3-2. The collectors labeled GA No. 2 were those which had their Lexan® covers removed. As can be seen clearly on Figure 3-3 that cluster's efficiency immediately increased from the worst to become the most efficient. This jump of 5 percent over the next most efficient group was a relative increase of 10 to 15 percent as predicted by General Electric in their specifications.

The evacuated tubes do not radiate large amounts of heat to melt off accumulated snow. If uncovered, the tubes and reflectors will also hold the snow and slow the removal process. It should be pointed out that the tubes were installed on an east-west orientation; this orientation tends to inhibit the snow removal process. The effect of snow becoming trapped within the collector vee-reflectors is illustrated in Table 3-2 and Figure 3-3 by the data from Julian dates 80 to 85. These data were collected during a severe snowstorm and show the only occurrence of lower efficiency by the second cluster during the period that its covers were removed. On Julian dates 82 and 83, the second cluster was slightly less efficient than its

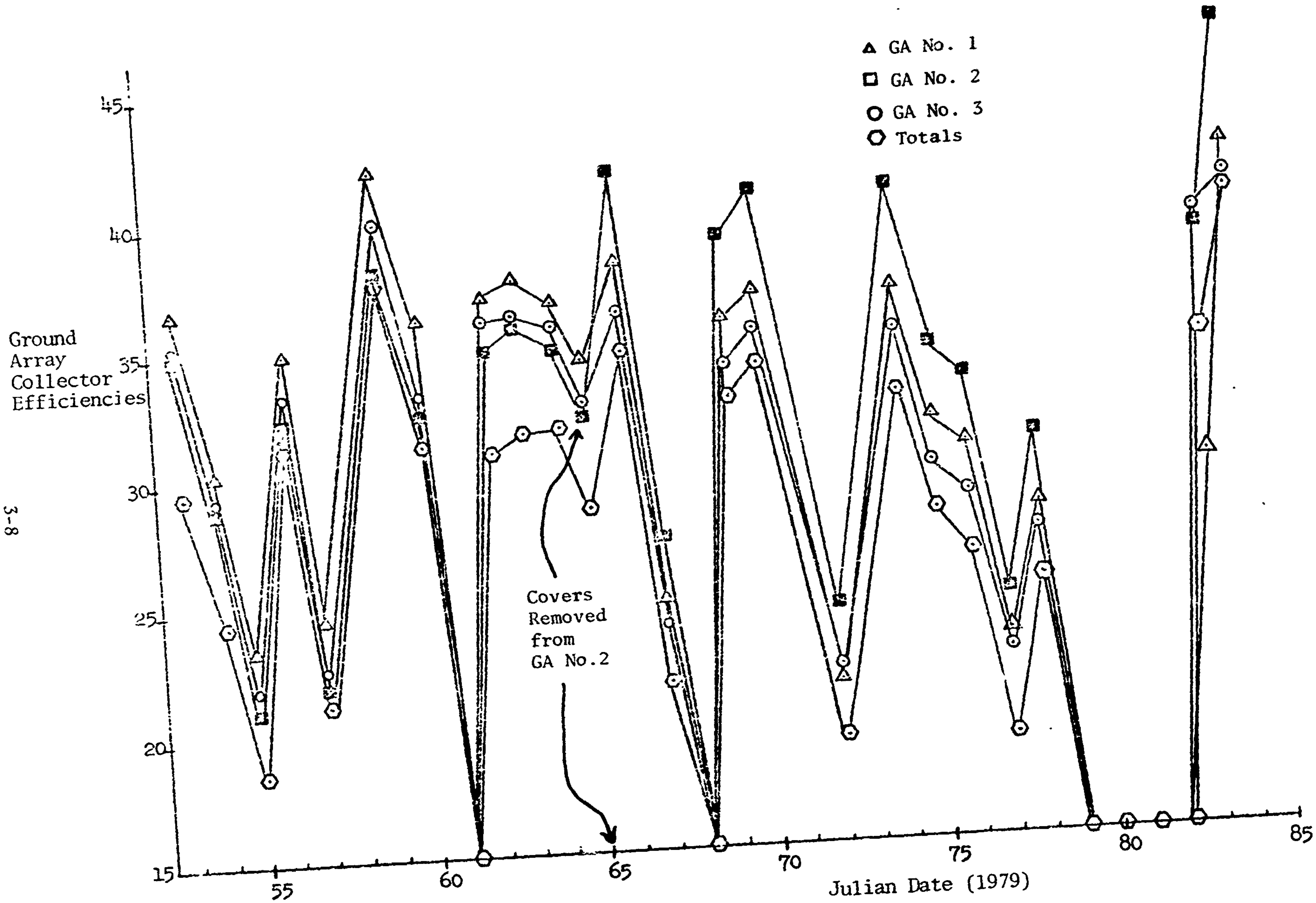


Figure 3-3. Lexan® Cover Removal Experiment Results

Table 3-2

Lexan® Cover Removal Data

Julian Date (1979)	GA No. 1	GA No. 2	GA No. 3	Total
53 - 22 Feb 79	36.7	34.8	34.9	29.5
54	30.3	28.0	28.1	24.3
55	23.6	21.1	21.9	18.6
56	34.9	32.1	33.2	31.2
57	24.5	21.7	22.6	21.1
58	--	--	--	--
59	41.8	38.0	39.7	37.7
60	36.0	32.3	33.0	31.1
61	14.3	12.2	13.0	9.6
62	36.8	34.6	35.9	30.7
63	37.4	35.6	36.0	31.3
64	36.5	34.7	35.5	31.8
65 - 6 Mar 79	34.2	32.1	32.3	28.4
66	38.1	41.4*	36.0	34.5
67	24.7	27.2	23.8	21.6
68	3.2	2.6	4.4	5.0
69	35.6	38.8	33.7	32.5
70	36.6	40.6	35.1	33.9
71	--	--	--	--
72	21.3	24.2	21.9	18.1
73	--	--	--	--
74	36.6	40.5	34.9	32.5
75	31.4	34.2	29.5	27.8
76	30.3	33.0	28.5	26.2
77	22.9	24.5	22.4	18.9
78	27.9	30.7	27.0	25.0
79	0.0	0.0	0.0	0.0
80	0.0	1.4	3.8	0.5
81	0.0	0.0	0.0	0.0
82	6.9	10.1	14.4	9.7
83	29.5	39.3	39.7	34.3
84 - 25 Mar 79	41.5	46.9	40.1	39.9

* Lexan® covers removed on the evening of 6 March 1979

neighbors because of the snow trapped within the reflectors. When the snow melted, the second cluster went back up to the highest efficiency position.

One collector cover was left off for an extended period in an effort to determine the resistance of the glass tubes to hail damage. A short duration storm did occur in late spring of 1979; the hailstones approached 1/2 to 3/4 inches in size. No breakage of glass occurred. This observation tends to support the specifications provided by the manufacturer regarding hail resistance.

One more comparison of the effect of the Lexan® covers on performance was made by comparing results before and after the cover removal. Table 3-3 shows the results of data analysis on both sides of 6 March 1979. This analysis takes into consideration the overall effect of the second collector cluster's (GA No. 2) increase in efficiency from the first period to the second with respect to environmental effects. The roof array efficiency dropped by almost 28 percent while the ground array went down only 8 percent. This change can perhaps be partially attributed to the smaller effect of outside air temperature on performance of evacuated tube collectors. However, the increase in efficiency of the coverless second cluster definitely contributed to the better performance of the ground array when compared to the roof array over this time period. If all collectors were uncovered on the ground array, it could even have led to an actual increase in overall ground array performance.

In conclusion, the added expense of the Lexan® covers (approximately $900 of the total evacuated tube collector cost of $5000) would not appear warranted in most areas. In those areas where severe storm damage or vandalism is of serious concern it would seem appropriate to use a much lower cost cover than the Lexan®. This conclusion is particularly true

Table 3-3

Lexan® Cover Removal Effects on Collector Efficiencies

Parameter	Period of Time	
	22 Feb to 6 Mar (All covers on)	7 Mar to 25 Mar (No covers on GA No.2)
Ground Array (Evacuated Tubes):		
Available Energy	4128 MJ	4571 MJ
Collected Energy	1137 MJ	1160 MJ
Efficiency	27.5%	25.4%
Roof Array (Flat-Plates):		
Available Energy	4998 MJ	5534 MJ
Collected Energy	2469 MJ	2018 MJ
Efficiency	49.4%	36.5%
Total (Combined Arrays):		
Available	9126 MJ	10105 MJ
Collected	3606 MJ	3178 MJ
Efficiency	39.5%	31.4%

Change in Efficiency Between Periods:

Ground Array:	-2.1/27.5 = -7.6%
Roof Array:	-12.9/49.4 = -27.8%
Total:	-8.1/39.5 = -20.5%

in view of the efficiency penalties that are incurred through the use of the Lexan® covers. A north-south, i.e., vertical not horizontal, orientation of the evacuated tubes would probably have minimized the concerns expressed above regarding snow entrapment during storm periods.

4.5 Summary

The following comments summarize the performance and characteristics of the evacuated tube collectors:

a. For this application, their efficiency was not as high as that obtained by double-glazed, nonselective surface, flat plate collectors.

b. They generally tried to start operation earlier in the day than the flat plates, but would cycle on and off frequently. They would generally remain on at the same time that the flat plates would start operation. (Cycling of the roof array flat plates occurred but not frequently.) The additional energy collected by the evacuated tubes (versus the flat plates) in this start-up mode was considered to be insignificant.

c. The evacuated tube collectors would shut down earlier in the afternoon. This observation is contrary to widely reported results of their operation.

d. Very limited evidence is available to support the contention that evacuated tubes out-perform flat plates on marginal insolation days. In fact, several instances of the flat plates running longer than the evacuated tubes on cloudy days occurred. This observation must be tempered by the realization that the roof and ground array installations were not identical. For example, the evacuated tubes on the ground array were much further from the storage tank and were also more exposed to the

ambient weather conditions; these and other factors could have resulted in the evacuated tubes not performing as well as the flat plates. It seems fair, however, to conclude that the often stated intrinsic advantages of evacuated tubes during marginal days were not sufficient to overcome other system disadvantages that may have been present. (It must also be pointed out that the ground array was more efficient than the roof array when both arrays consisted of flat plate collectors.)

e. It is believed that higher quality workmanship and materials are required during the installation of an evacuated tube collector system.

f. Maintenance requirements were significantly greater for the evacuated tube collector array than for the installed flat plates. Some glass shrouds broke for no apparent reason and their replacement, though not difficult, was a time-consuming task and irritant.

g. Performance was increased when the Lexan® covers were removed. It would seem advisable not to use Lexan® covers in areas not susceptible to severe hailstorms or vandalism. It would also appear reasonable to use a cheaper cover, if available, for those installations that require a protective cover system.

h. The cost of the GE TC-100 collectors (FOB from the factory) was approximately \$20.00 per ft^2 in 1978. The cost of the Revere flat plate collectors was approximately \$8.80 per ft^2 in 1975. It would seem that no performance benefits accrued despite their higher cost.

CHAPTER 4

LOSS OF ENERGY SITUATION - SIMULATION (LESS)

4.1 Introduction

With disturbing frequency, natural gas and fuel oil shortages have occurred in various areas of our country. During these emergencies homeowners have been requested to turn down their thermostats to save energy and decrease fuel demands. Since the USAFA Solar Test House was so well instrumented and since it had an operational solar energy system to supply a portion of the thermal energy to heat the structure, the researchers decided to operate the house as though it had been completely cut off from natural gas. This experiment was called the Loss of Energy Situation - Simulation (LESS) and was conducted during February 1979.

4.2 Procedure

This experiment took advantage of the energy conservation techniques that have been applied to the structure. These are discussed in previous technical reports and consist of urea formaldehyde foam added to the walls; additional insulation added to the roof; added vestibules; and triple-glazed windows. In addition, the data gathering and microprocessor control systems allowed complete control over the use of the natural gas supply without actually cutting it off. Thus, the microprocessor was programmed not to use natural gas unless the house temperature reached 10^{o}C (50^{o}F). This temperature was selected only to protect the plumbing system. The control program was changed to use the energy in the solar storage tank until it was no longer able to hold the house at 10^{o}C. The desired house temperature was changed to 15.5^{o}C (60^{o}F) on the first day of the test to simulate a setting that a family might use during this type of emergency.

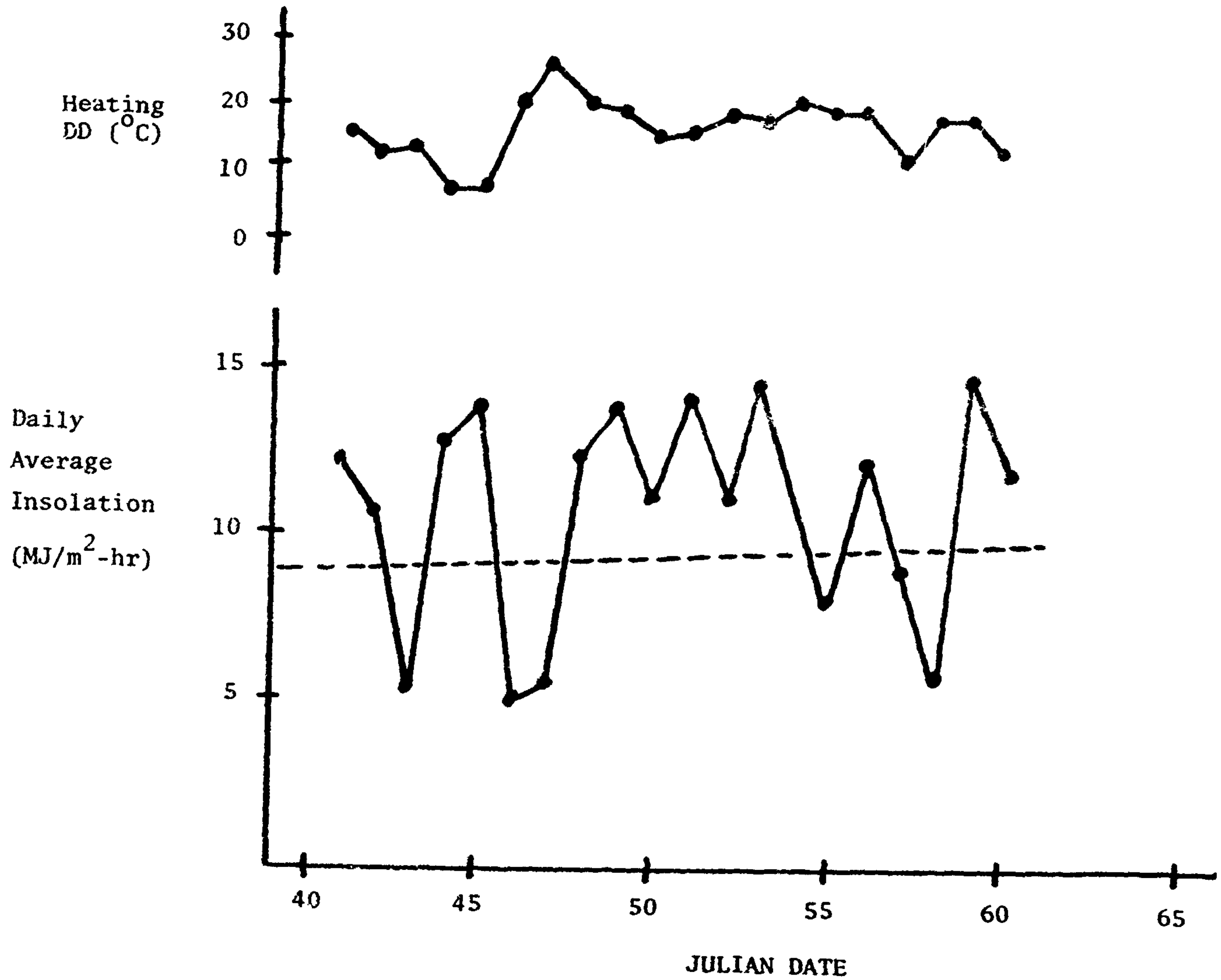


Figure 4-1. Environmental Conditions During LESS

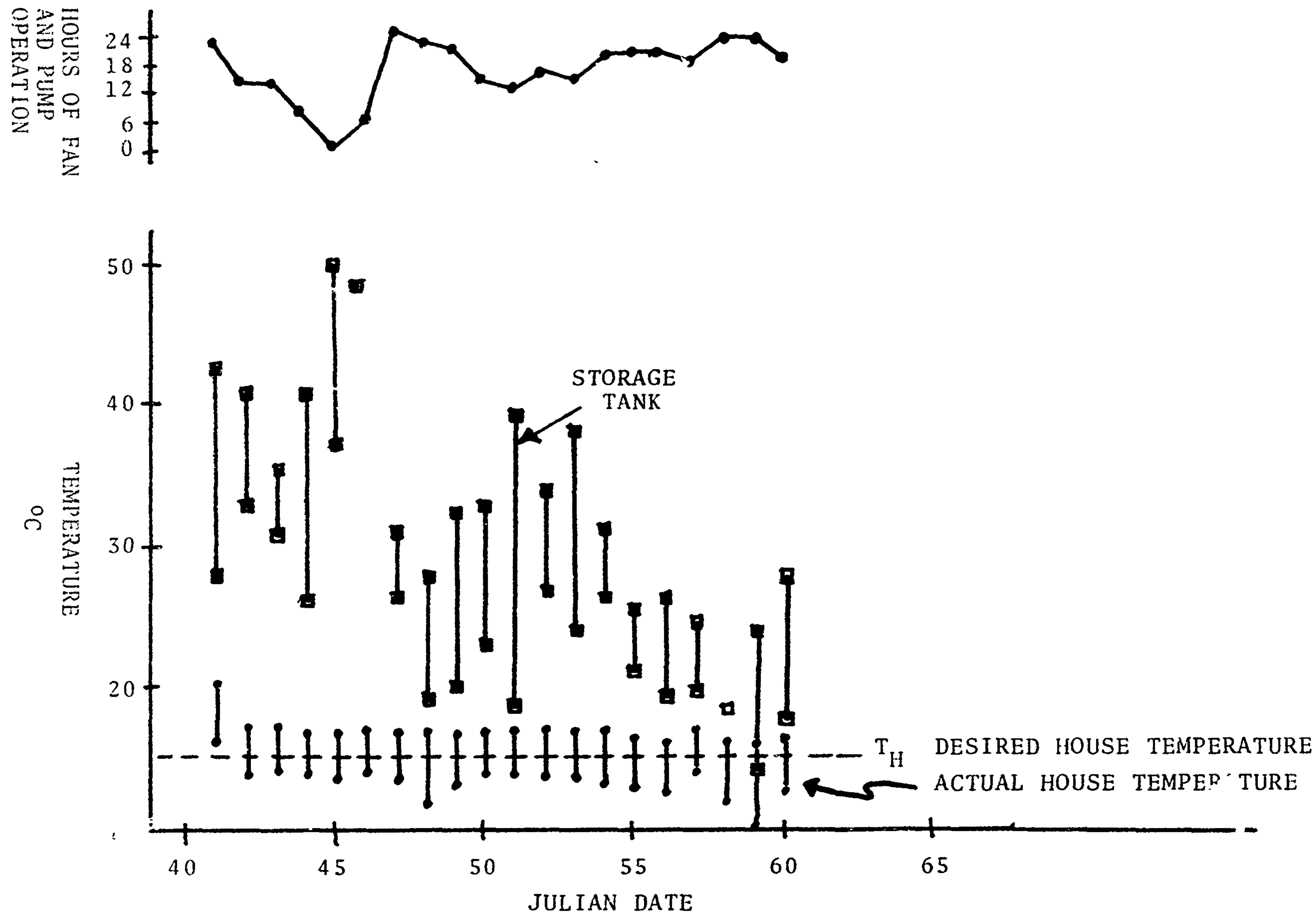


Figure 4-2. System Performance During LESS

4.3 Results

LESS started on 10 February 1979 and stopped on 1 March 1979. These dates were chosen so that a comparison could be made with the data from February 1978 when the house was also unoccupied. The choice for the starting date was also influenced by the time taken to reprogram the microprocessor and the severity of the two preceding months' weather. Figure 4-1 shows the environment that existed during LESS. The upper chart shows the degree days that were recorded from Julian Date 41 (10 Feb 79) to Julian Date 60 (1 March 79). The lower graph illustrates the variable nature of insolation over this period of time while the dotted line shows the steady increase of the daily average. There was a total of 332 ^{o}C-days (595 ^{o}F-days) during LESS while the daily average insolation level was 9.7 MJ/m^2-hr (horizontal).

The performance data gathered during the test is plotted in Figure 4-2. The desired house temperature (T_H desired) was maintained at 15.5^{o}C (60^{o}F) almost every day within the dead band of the sensors and the tolerance of the control program. Only on Julian Date 59 did the low temperature reach 10^{o}C (50^{o}F) and only then during the very early morning hours for a short period. On Julian Date 48 the temperature also dipped, reaching a minimum of 11^{o}C (52^{o}F). Additionally, both of these days were also characterized by low storage tank temperatures. The latter date (Day 59) also demonstrated the effects of the steady lowering tank temperature over the entire period.

During Day 59 the solar system could not maintain the house at the desired temperature because the storage tank temperature itself went below 15.5^{o}C to 14^{o}C (60^{o}F to 57^{o}F). As the storage temperature continued downward, the pump and fan ran for long periods as is shown in the upper graph

in Figure 4-2. The solar energy input to the house just offset the structure's energy loss to the environment and would not raise the house temperature above 15.5°C (60°F) at night. However, the solar system maintained the house at a relatively comfortable temperature the vast majority of the time with no internal energy from occupation contributing to the thermal energy supply.

4.4 Conclusion

In conclusion, LESS demonstrated that a typically sized, solar energy space heating system can supply almost 100 percent of a reduced energy demand in case of a natural gas or oil cutoff. Only on two occasions did the indoor temperature go below the minimum setting and only then for a short period of time. Therefore, a solar home occupant can survive relatively comfortably during winter weather until the supply of auxiliary energy is restored. This assumes that electrical service for parasitic system power requirements is still available.

CHAPTER 5

FINAL SYSTEM CONFIGURATION

5.1 Introduction

As the research project drew to a close (funding ceased on 30 Sep 79) increased attention was given to actions which would make the installed solar system as efficient and maintenance-free as possible prior to its turnover for normal occupancy. Since the evacuated tube collectors had not proven effective for this project from either a maintenance or efficiency standpoint, the researchers decided to remove them and reinstall the flat plate collectors. In contrast, the flat plate collectors possessed proven reliability and had not required any maintenance or repair.

Another major task requiring accomplishment was the fabrication and installation of a simple, low cost and reliable solar controller. This was necessary due to the planned removal of the instrumentation and control system which had been used to support data gathering.

The following sections discuss these and other tasks which were accomplished prior to returning the home to the control of the Base Civil Engineer.

5.2 Ground Array Final Configuration

In September 1979 the evacuated tube collectors were removed and the flat plates were reinstalled. The reinstallation of the flat plate collectors implemented the following lessons learned.

Flow balancing had always been difficult, so reverse return plumbing was considered a necessity. In addition, rather than have some of the parallel collector clusters consist of three collectors and some of four,

the researchers decided to use three parallel clusters of four collectors each. This action also helped balance head loss and therefore flow rate through all collectors. This scheme resulted in only 12 collectors ($21.7m^2$-234 ft^2) being installed versus the 14 ($25.4m^2$-273 ft^2) which had been formerly used. (The original 14-collector installation on the roof array was not changed.) It was believed that this modification would not noticeably detract from the performance of the system.

An effective air bleed system was also provided as a part of the reinstallation.

The work was accomplished by craftsmen assigned to the civil engineering squadron using design sketches and material provided by the research team. No unusual problems were encountered and the work was completed on schedule.

Other miscellaneous plumbing work was also accomplished at this time. Loss of energy due to thermosiphoning from the storage tank to the roof array, which had been observed, was stopped by installing check valves in the supply and return lines. The roof array collector fluid sensor was also moved under the array's sheet metal flashing for protection from the weather. All fluid temperature sensors were also isolated by valves; this innovation permits any sensor to be replaced without completely draining the fluid.

Details of the final ground array configuration are shown in Appendix B.

5.3 Instrumentation and Control System Final Configuration

The instrumentation and control system was dismantled during this report period and replaced with a mini-microprocessor-based control system. The original control and instrumentation systems are described

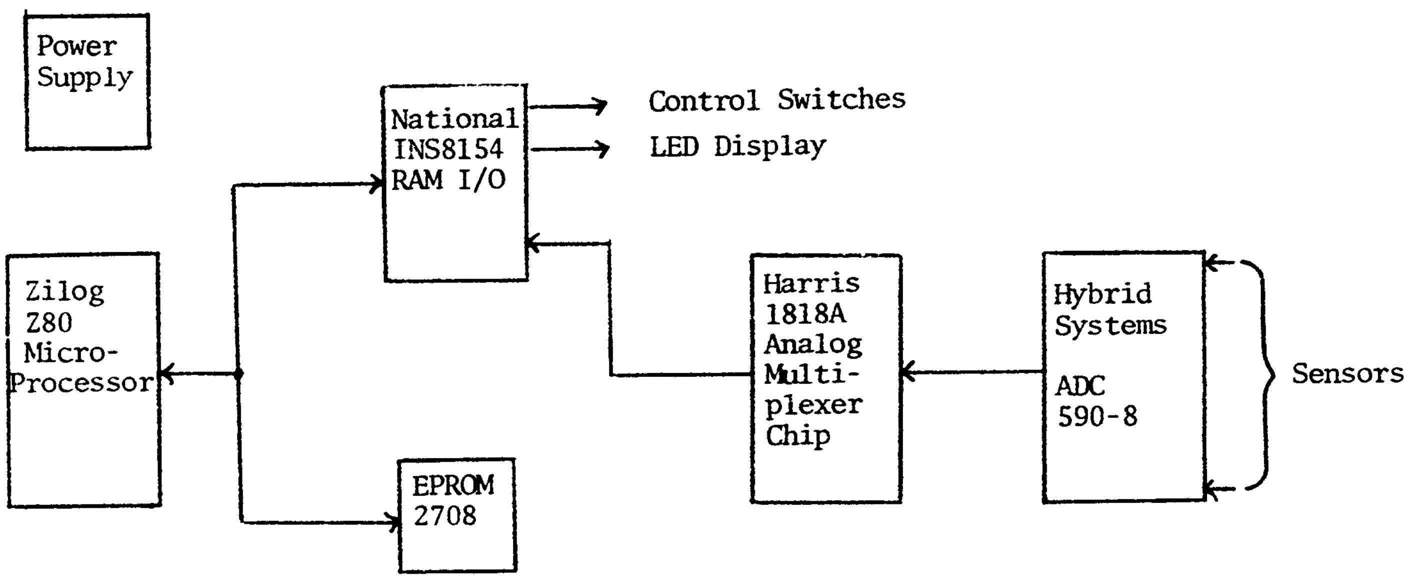


Figure 5-1. Functional Block Diagram of Solar Controller

in previous technical reports (1, 2, 3). The replacement for this system was installed and tested in the early summer of 1979 and has functioned successfully since that time. All data gathering was suspended when the mini-micro system controller installation was begun.

As described in the third interim technical report (3), a project was undertaken to build a microprocessor-based controller to operate the solar system in a normal-home heating mode. Since no further data gathering was needed for the project, a small mini-computer was designed and installed to operate the system. Second Lieutenant Michael L. Baumgartner, then a cadet, designed the basic system shown in the functional block diagram in Figure 5-1. A complete wiring diagram is shown in Appendix C.

The micro-computer used in the system is a Zilog Z-80. Random Access Memory (RAM) is provided to the system by a National INS 8154 RAM-I/O chip. This chip provides 128 bytes of memory and 16 I/O lines for controlling the house. Program storage is provided by a 2708 EPROM which holds 1024 bytes of memory. The 16 I/O lines of the INS 8154 provide two ports--one for signal input and one for output. Port B uses eight I/O lines for output only. Port A uses the remaining eight lines as a bi-directional I/O bus. The output data to control the house operation is placed at Port A. Then one line of Port B, PB4, is pulsed high-low-high to latch the data into the 74LS374 (see wiring diagram in Appendix C). Sensor information is input to Port A when the correct address for the channel desired is given to the H1818, AMUX; PB5 is brought low to start the conversion from analog to digital, ADC, and enable the 81LS95 to latch the data to Port A. Prior to this, Port A has been reconditioned as an input port. After a time delay for conversion of data, the information is read into Port A and stored in memory. The

system is totally memory mapped, that is, all devices including I/O are treated as memory. An ambiguous addressing scheme is used to select the desired peripheral device. The addressing is as follows:

0000H	-	03FFH	PROM
0C00H	-	0C7FH	RAM
0800H	-	087FH	I/O

The basic control program for the solar controller is a modification of the original program shown in the first interim technical report (1). A complete listing of the present program is included in Appendix C. The program was simplified since there are no variable flow control valves located in either collector array and the sensors on the ground array are now being used to control both arrays. In an effort to simplify the system the designers reduced the total number of sensors even further. Some operations done by the original system, therefore, have been implemented in software for the present system. These changes have been made using the experience gained from previous research.

Figures 5-2 through 5-4 contain the flow chart for the main portions of the control program. The task scheduler initializes all control parameters and calls all subroutines needed for control of the house. These subroutines are called approximately every second which corresponds to a visible Activity Light Emitting Diode (LED) changing states, i.e., blinking on and off. The ground array routine (Figure 5-3) is basically the same as it was in the original program. As stated previously, the main difference is that this routine now controls both the ground and roof array collector operation. This was done for ease of maintenance due to the difficulty in replacing the roof array sensors in the event of their failure. It was determined that this method of operation would result in

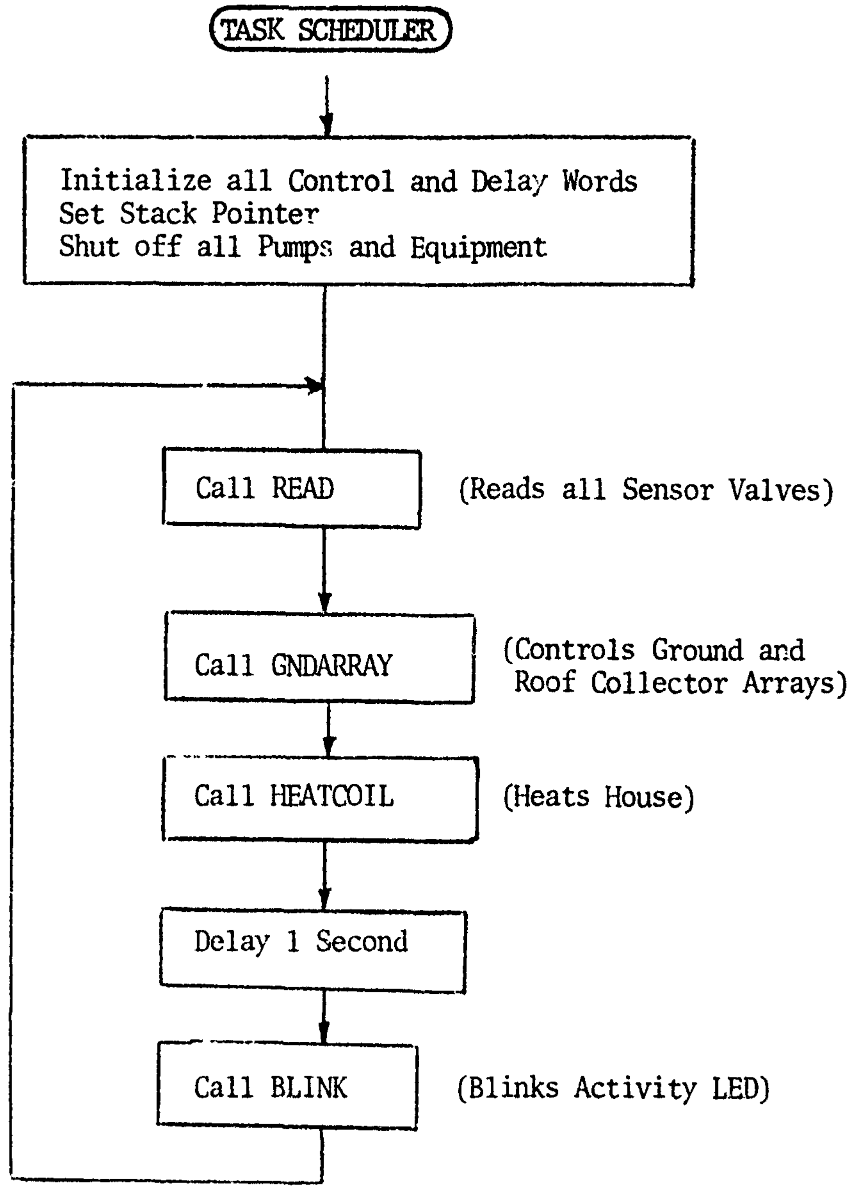


Figure 5-2. Task Scheduler Flow Chart

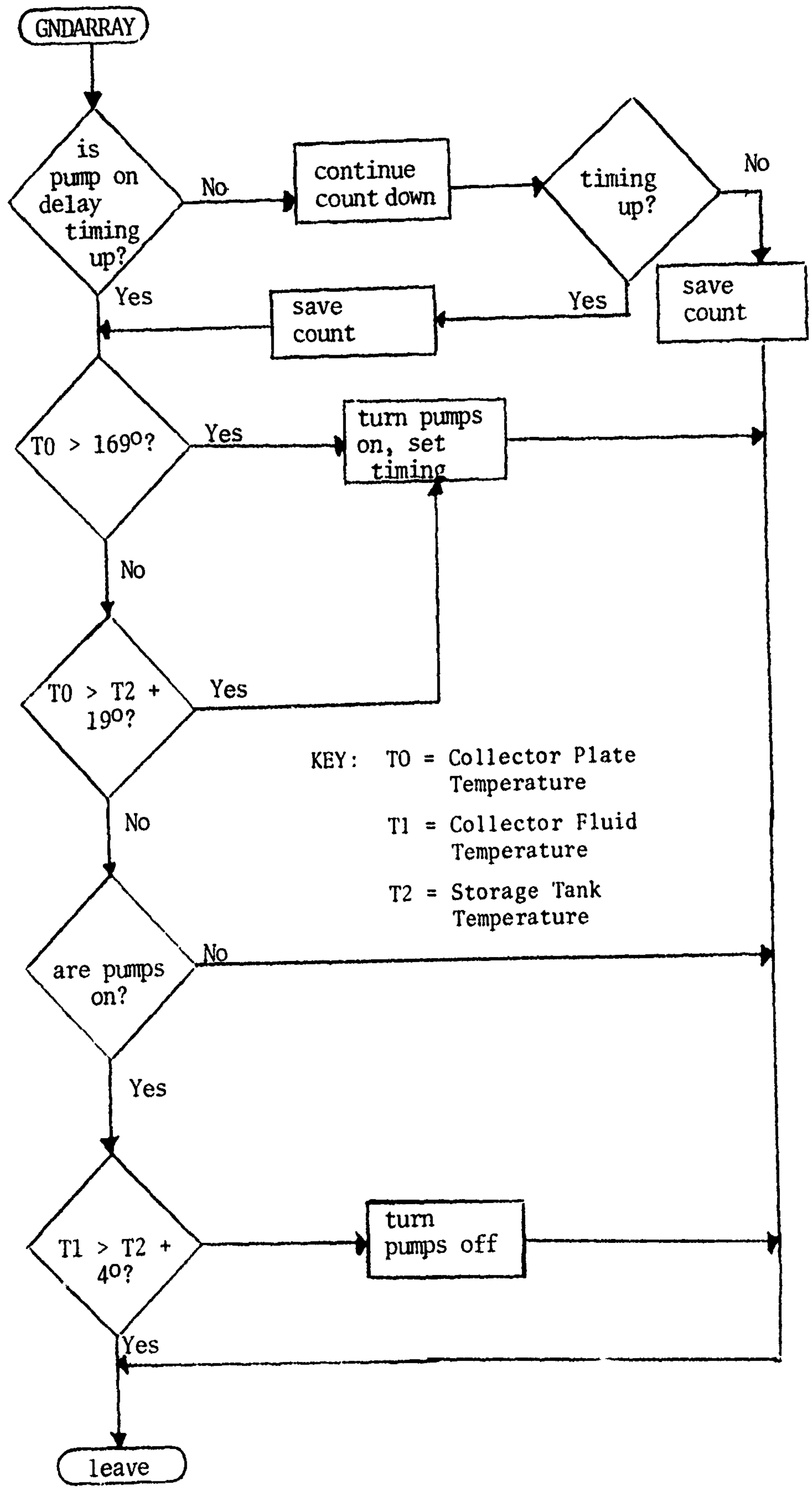
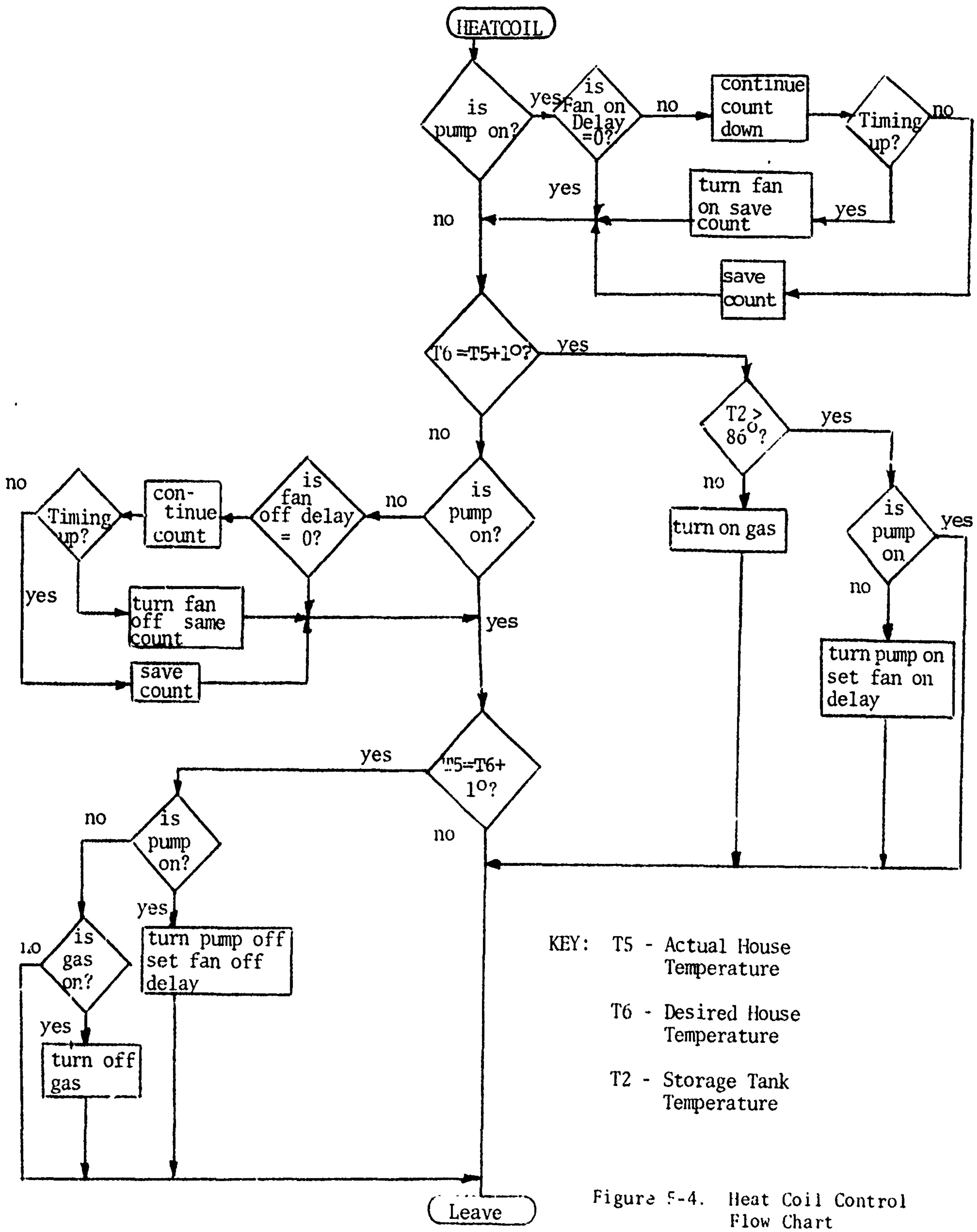


Figure 5-3. Ground Array Control Flow Chart



KEY: T5 - Actual House Temperature

T6 - Desired House Temperature

T2 - Storage Tank Temperature

Figure 5-4. Heat Coil Control Flow Chart

minimal energy loss during start-up or shutdown. A time delay has also been placed in this routine whenever the collector array pumps are turned on. This time delay, of about one minute, is used to keep the pumps from cycling on and off during start-up. This is used primarily for occupant convenience. It was felt that the cycling, which sometimes occurred on the old system, might cause some concern with the occupants. The change should also help extend pump life. The heating program is the other subroutine and is shown in Figure 5-4. To eliminate additional control sensors, two additional timing routines were used. Both of these routines have to do with the fan being turned on and off. To allow the hot storage tank water to reach the heat exchanger in the return air plenum a delay is set when the storage tank pump is turned on. After this delay, about 40 seconds, the fan is turned on. Also, to completely remove energy from the heat coil after pump shutdown, the fan stays on for approximately 40 seconds after the pump is turned off.

Other routines used in the program are specific to the hardware being used. They are not unique and depend upon the devices chosen to perform the specific task.

The operation of the present system was designed for an occupant with no technical background, and to be maintained by base-level civil engineering forces. Figure 5-5 shows the coverplate of the mini-microprocessor solar controller. The controller is located in the basement of the house on a wall adjacent to the pumps and associated equipment. The solar controller utilizes a temperature sensor in the house, and an internal thermostat to control the house temperature by using either solar energy or the gas furnace. A conventional wall-mounted thermostat located in the living room still functions normally with the gas furnace. This

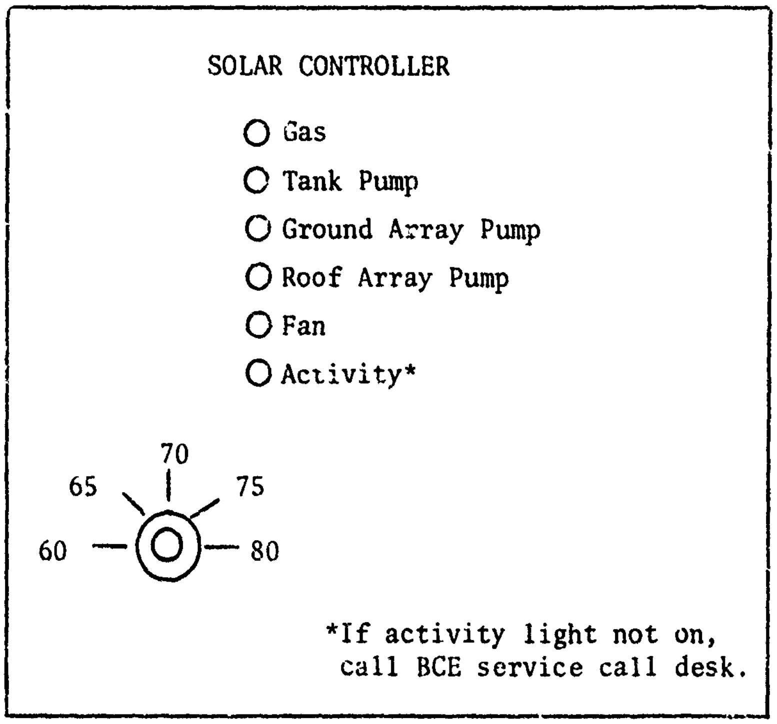


Figure 5-5. The "Mini-Computer" Solar Controller

thermostat must always be at a lower setting (at around 50-55^{o}F) than the solar controller thermostat during normal operation. If operated in this manner it will become apparent immediately if the solar controller, or the solar system, is malfunctioning. Put simply, the house will get cold. If this occurs the occupant will notify civil engineering maintenance forces. Until repairs are made, the conventional thermostat can be raised and the home will be heated solely by the gas furnace just like any other house.

The LED's (Light Emitting Diodes) on the solar controller give a visual display of system operation. The Activity LED, if blinking, shows that the microcomputer is operating normally. The other LED's, if on, indicate that the applicable mechanical unit is functioning. As indicated on Figure 5-5, if the Activity LED is not blinking, the occupant is instructed to call civil engineering maintenance personnel. In addition, if actual system operation does not agree with the controller LED display (e.g., tank pump LED on but the pump is not on, etc.) the occupant should call for maintenance assistance. The following chapter discusses maintenance and operation in greater detail.

CHAPTER 6

HOMEOWNER AND MAINTENANCE MANUAL DEVELOPMENT

6.1 Introduction

Solar projects in the civilian sector have too often been victimized by an "install it and forget it" attitude. Active solar systems can't be abandoned if they are to provide good service throughout their design life. Although most solar systems aren't complex or inherently difficult to maintain, they still represent a mystery to most craftsmen. Similarly, many typical homeowners will have no technical understanding of solar systems. The combination of these two factors, if not overcome, can result in efficient operation and early failure of solar projects.

6.2 Maintenance Manual Development

When the research project was drawing to a close, the researchers perceived a need to prepare an operation and maintenance manual for use by civil engineering personnel. A manual was required because the maintenance had been mostly performed by the research team and Base Civil Engineering craftsmen had not had the opportunity to learn the system. It was not considered enough, therefore, to simply enter one-line descriptions of required tasks in the recurring maintenance schedule; a manual describing why, when, and how these tasks had to be accomplished was prepared. The entire manual appears in Appendix D.

The manual covers routine scheduled maintenance such as checking freeze protection in collector circuits, cleaning pipe strainers, pump lubrication, checking pressure relief valves and other similar tasks. Detailed instructions on system draining and recharging are included;

all valves and pumps are clearly labeled on the system and the instructions are keyed to these labels.

Since most civil engineering craftsmen have no familiarity with solid state controllers a significant portion of the manual is devoted to a "troubleshooting checklist" for the controller. A control diagram showing the location of all system sensors and typical signal outputs is included. Considerable detail is also included which should permit an electrician unfamiliar with solid state technology to actually repair a malfunctioning controller with available spare parts that were provided.

In conclusion, it is strongly recommended that a similar manual be provided for all projects which will be maintained by in-house forces.

6.3 Homeowner Manual Development

A knowledgeable homeowner or facility custodian who is familiar with "his" solar system will help considerably in achieving proper system operation. A manual which explains the system in lay terms will help to achieve a knowledgeable occupant. The typical Air Force occupant may be less motivated towards solar than his civilian counterpart since he does not have a personal investment at stake. The manual should therefore try to motivate and be as short and simple as possible. The manual developed by the researchers is shown in Appendix E.

The key component of the manual is the section which explains the solar controller's visual display panel. The manual's descriptions of the typical operational modes which are displayed on the controller greatly aid a homeowner's understanding of the system. In effect, the facility occupant can troubleshoot the system himself.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The conclusions of the research during the last year of work are briefly summarized as follows:

a. The evacuated tube collectors used in this project were not as effective as flat plate collectors. They were more costly, required more care in installation and maintenance and were not as efficient in this application.

b. A microprocessor-based solar controller is economical, effective and reliable. The only disadvantage associated with their use is that they are not as well understood by most engineers and maintenance craftsmen. This may be a significant concern for the Air Force.

c. A solar space heating system can maintain a livable environment in a facility which has been cut off from conventional energy sources. This presupposes that electrical power to operate the system remains available during such an emergency.

d. An unoccupied residential facility requires more traditional space-heating energy (i.e., natural gas, fuel oil, etc.) than an occupied building. The energy gains associated with occupancy are considered to be a substantial portion of the total heating-energy budget of a small, well insulated structure.

e. The urea formaldehyde (UF) foam insulation used in this project has not begun to degrade or to produce formaldehyde gas. The UF foam had been in place for three years when the home was checked for the presence of vapors. (Despite this finding the researchers cannot

recommend widespread use of UF foam since its degradation has been reported in other locations.)

7.2 Recommendations

During the course of this project many lessons in several areas of solar technology have been learned. These lessons and many tips for designers have been consolidated in a final summary report for this project. The reader is referred to ESL-TR-80-35(4), available from NTIS, for these recommendations.

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APPENDIX A

SOLAR SYSTEM TABULARIZED
PERFORMANCE DATA SUMMARY

(May 1978 - April 1979)

Julian Date MAY	Solar Insolation MJ/M²/Day Cum,Horiz.	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance		
		Start °C	Finish °C	MJ Avail.	MJ Col.	%	MJ Avail.	MJ Col.	%
121	4.6	24	23	85	0	0	85	0	0
122	3.9	23	22	71	0	0	71	0	0
123	11.0	21	26	203	82	41	203	47	23
124	11.5	24	27	196	81	41	196	29	15
125	2.0	26	26	38	0	0	38	0	0
126	1.4	24	24	34	0	0	34	0	0
127	10.0	23	27	175	0	0	175	0	0
128	13.1	26	28	221	96	43	221	-1	0
129	26.3	26	27	440	329	75	440	53	12
130	21.9	12	29	359	307	86	359	125	35
131	20.6	27	38	333	232	70	333	166	50
132	23.2	32	46	380	250	66	380	199	52
133	25.8	38	48	427	276	65	427	154	36
134	23.1	42	53	374	227	61	374	201	54
135	17.5	51	56	281	148	53	281	129	46
136	22.6	52	60	376	194	52	376	170	45
137	9.9	56	56	162	0	0	162	0	0
138	26.6	46	54	431	233	54	431	186	43
139	23.1	48	55	368	198	54	368	168	45
140	21.2	53	56	395	166	46	359	148	41
141	10.1	50	48	170	1	1	170	2	1
142	18.4	41	46	301	103	34	301	69	23
143	16.1	41	46	261	82	31	261	57	22
144	25.4	42	52	910	220	24	910	141	16
145	21.5	47	50	318	152	48	318	53	17
146	21.0	47	51	319	164	51	319	70	22
147	12.9	48	47	173	27	16	173	5	3
148	16.3	44	44	263	118	45	263	81	31
149	21.1	37	43	319	203	64	319	78	25
150	22.0	39	44	155	162	46	355	80	22
151	10.8	39	39	146	0	0	146	1	0
TOTALS	13.3	37	41	8852	4055	46	8852	2411	27

Julian Date MAY	Degree Days (°F)	House Heating Demand (MJ)				Time Interval Analysis	Avg Hourly Heating Demand MJ/Hour
		Total	Solar	Gas	% Solar		
121	27	212	37	175	17	24	8.83
122	30	254	0	254	0	23	11.11
123	24	202	0	202	0	24	8.60
124	22	201	0	201	0	24	8.32
125	32	216	0	216	0	23	9.22
126	32	138	0	138	0	14	9.68
127	31	132	0	132	0	14	9.43
128	25	188	0	188	0	23	8.25
129	26	193	48	145	25	23	8.25
130	12	116	20	96	17	23	4.98
131	4	46	0	46	0	24	1.92
132	15	124	124	0	100	23	5.44
133	14	103	103	0	100	23	4.48
134	4	76	76	0	100	23	3.31
135	2	32	32	0	100	21	1.51
136	5	0	0	0	0	20	0.00
137	11	50	50	0	100	20	2.43
138	11	147	147	0	100	22	6.57
139	7	98	98	0	100	23	4.27
140	8	74	74	0	100	23	3.27
141	10	108	108	0	100	24	4.49
142	7	81	81	0	100	24	3.42
143	5	66	66	0	100	22	2.95
144	5	17	17	0	100	23	0.72
145	6	61	61	0	100	23	2.62
146	1	15	15	0	100	23	0.65
147	12	72	72	0	100	24	3.01
148	16	61	61	0	100	16	3.70
149	10	88	88	0	100	23	3.85
150	4	51	51	0	100	23	2.21
151	17	159	159	0	100	23	6.84
TOTALS	435	3381	1587	1795	47	687	4.92

Julian Date JUNE	Solar Insolation MJ/M^2/Day Cum,Horiz.	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance		
		Start °C	Finish °C	MJ Avail.	MJ Col.	%	MJ Avail.	MJ Col.	%
152	4.0	31	28	62	0	0	62	0	0
153	1.0	27	27	18	0	0	18	0	0
154	2.4	34	25	111	0	0	111	0	0
155	6.5	24	26	87	27	31	87	8	10
156	---	--	--	---	---	--	---	---	--
157	13.6	24	38	194	75	39	194	42	21
158	12.3	31	37	190	99	52	190	54	29
159	10.6	35	44	157	105	67	157	63	40
160	25.4	38	47	362	216	60	362	123	34
161	23.5	44	51	340	184	54	340	109	32
162	25.1	49	54	386	214	56	386	96	25
163	21.0	51	56	290	115	40	290	71	24
164	20.5	49	57	286	124	44	286	86	30
165	22.1	50	60	322	161	50	322	106	33
166	25.2	53	62	355	185	52	355	129	36
167	26.4	54	64	386	197	51	386	144	37
168	20.3	59	62	306	100	33	302	77	25
169	21.0	54	61	319	128	40	319	87	27
170	12.2	55	62	181	91	50	181	58	32
171	16.7	55	60	344	96	39	244	77	32
172	10.6	54	53	151	36	24	151	22	14
173	5.4	61	61	68	29	43	68	15	21
174	25.0	54	62	360	163	45	360	89	25
175	21.0	55	61	297	110	37	297	58	20
176	27.1	54	65	394	185	47	394	174	44
177	22.8	57	66	342	138	41	342	125	37
178	15.6	56	62	236	53	23	236	43	18
179	23.4	57	64	357	144	40	357	134	38
180	14.2	57	58	199	24	12	199	15	7
181	13.5	52	58	221	83	37	221	54	24
TOTALS	15.8	47	52	7217	3084	43	7217	2057	29

Julian Date JUNE	Degree Days (°F)	House Heating Demand (MJ)				Time Interval Analysis	Avg Hourly Heating Demand MJ/Hour
		Total	Solar	Gas	% Solar		
152	18	207	144	62	70	24	8.62
153	18	36	0	36	0	7	5.19
154	14	71	0	71	0	17	4.12
155	15	47	0	47	0	14	3.36
156	16	--	--	--	--	--	--
157	24	61	0	61	0	18	3.37
158	--	98	98	0	100	15	6.75
159	--	23	23	0	100	10	2.22
160	--	69	69	0	100	24	2.89
161	--	0	0	0	0	24	0.00
162	--	0	0	0	0	17	0.00
163	--	0	0	0	0	22	0.00
164	--	17	17	0	100	24	0.72
165	--	0	0	0	0	23	0.00
166	--	0	0	0	0	24	0.00
167	--	0	0	0	0	23	0.00
168	--	0	0	0	0	23	0.00
169	--	-	-	-	-	24	0.00
170	--	0	0	0	0	19	0.00
171	--	0	0	0	0	21	0.00
172	--	0	0	0	0	12	0.00
173	0	0	0	0	0	9	0.00
174	0	0	0	0	0	24	0.00
175	0	0	0	0	0	24	0.00
176	0	0	0	0	0	24	0.00
177	0	0	0	0	0	24	0.00
178	0	0	0	0	0	24	0.00
179	0	0	0	0	0	24	0.00
180	0	0	0	0	0	24	0.00
181	3	0	0	0	0	24	0.00
TOTALS	108	629	352	277	56	586	1.07

Julian Date JULY	Solar Insolation MJ/M^2/Day Cum,Horiz.	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance		
		Start °C	Finish °C	MJ Avail.	MJ Col.	%	MJ Avail.	MJ Col.	%
182	23.7	51	59	344	139	40	344	90	26
183	24.3	52	60	348	156	45	348	75	21
184	26.8	53	61	382	183	48	382	82	22
185	27.4	54	66	1942	191	10	1942	179	9
186	25.6	58	68	580	172	30	580	164	28
187	19.8	59	65	397	83	21	397	87	22
188	21.4	59	67	300	109	36	300	99	33
189	24.0	60	67	413	144	35	413	127	31
190	15.1	59	63	256	55	21	256	56	22
191	14.0	56	58	222	19	9	222	18	8
192	18.4	53	57	280	96	34	280	81	29
193	19.5	52	59	308	105	34	308	87	28
194	16.0	54	59	244	91	37	244	82	34
195	18.1	52	64	285	122	43	285	124	43
196	17.2	56	62	266	85	32	266	79	30
197	17.0	54	60	258	80	31	258	77	30
198	18.3	53	55	275	55	20	275	54	20
199	20.3	51	60	310	129	41	310	115	37
200	16.6	54	60	277	108	39	277	108	39
201	16.1	54	56	232	39	17	232	36	16
202	18.0	51	56	273	92	34	273	90	33
203	6.1	51	60	86	7	8	86	4	4
204	20.9	52	62	346	146	42	346	145	42
205	24.2	54	67	379	190	50	379	182	48
206	19.4	58	67	308	127	41	308	128	42
207	21.3	59	68	351	152	43	0	0	0
208	16.3	60	59	269	106	39	0	0	0
209	18.1	62	67	410	76	19	0	0	0
210	13.5	59	67	268	82	31	0	0	0
211	17.5	54	64	299	140	47	0	0	0
212	15.6	56	63	272	89	33	0	0	0
TOTALS	14.2	55	62	11181	3366	30	9312	2371	25

Julian Date JULY	Degree Days (°F)	House Heating Demand (MJ)				Time Interval Analysis	Avg Hourly Heating Demand MJ/Hour
		Total	Solar	Gas	% Solar		
182	0	0	0	0	0	0	0.00
183	0	0	0	0	0	0	0.00
184	0	0	0	0	0	0	0.00
185	0	0	0	0	0	0	0.00
186	0	0	0	0	0	0	0.00
187	0	0	0	0	0	0	0.00
188	0	0	0	0	0	0	0.00
189	0	0	0	0	0	0	0.00
190	1	0	0	0	0	0	0.00
191	1	0	0	0	0	0	0.00
192	0	0	0	0	0	0	0.00
193	0	0	0	0	0	0	0.00
194	0	0	0	0	0	0	0.00
195	0	0	0	0	0	0	0.00
196	0	0	0	0	0	0	0.00
197	0	0	0	0	0	0	0.00
198	0	0	0	0	0	0	0.00
199	0	0	0	0	0	0	0.00
200	0	0	0	0	0	0	0.00
201	1	0	0	0	0	0	0.00
202	3	0	0	0	0	0	0.00
203	5	13	13	0	100	17	0.73
204	3	42	42	0	100	23	1.80
205	0	0	0	0	0	0	0.00
206	0	0	0	0	0	0	0.00
207	0	0	0	0	0	0	0.00
208	0	0	0	0	0	0	0.00
209	0	0	0	0	0	0	0.00
210	0	0	0	0	0	0	0.00
211	1	0	0	0	0	0	0.00
212	0	0	0	0	0	0	0.00
TOTALS	15	55	55	0	100	684	0.08

Julian Date AUGUST	Solar Insolation MJ/M^2/Day Cum,Horiz.	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance		
		Start °C	Finish °C	MJ Avail.	MJ Col.	%	MJ Avail.	MJ Col.	%
213	20.5	57	64	395	114	32	359	240	67
214	14.4	58	62	255	75	30	255	158	62
215	3.1	55	52	54	0	0	54	0	0
216	12.5	44	52	219	75	34	219	137	63
217	24.2	46	61	415	207	50	0	0	0
218	13.3	54	61	231	89	38	231	181	78
219	24.6	57	68	424	190	45	0	0	0
220	18.1	62	64	307	76	25	307	57	18
221	0.0	59	64	0	0	0	0	0	0
222	15.4	60	61	261	37	14	261	23	9
223	18.6	55	63	333	120	36	333	81	24
224	18.8	56	63	342	129	38	342	87	25
225	18.7	57	64	339	124	37	339	66	19
226	21.4	57	67	426	149	35	426	78	18
227	24.6	58	68	457	190	42	457	107	23
228	23.1	59	69	438	299	46	438	111	25
229	22.6	62	71	440	188	43	440	99	23
230	---	--	--	---	---	--	---	---	--
231	21.7	56	64	411	164	40	411	112	27
232	17.8	57	62	344	118	34	344	74	21
233	15.9	58	60	303	78	26	303	51	17
234	15.9	54	58	306	63	21	306	57	19
235	20.6	53	65	407	179	44	407	168	41
236	12.8	57	60	245	48	20	245	47	19
237	---	--	--	---	---	--	---	---	--
238	13.2	48	58	276	129	47	276	102	37
239	20.9	52	65	455	209	46	455	174	38
240	20.0	57	68	423	173	41	423	158	37
241	5.2	60	59	109	0	0	109	0	0
242	17.9	51	62	378	171	45	378	137	36
243	13.7	54	60	290	63	22	290	56	19
TOTALS	15.9	55	62	9247	3359	36	8408	2561	30

Julian Date AUGUST	Degree Days (°F)	House Heating Demand (MJ)				Time Interval Analysis	Avg Hourly Heating Demand MJ/Hour
		Total	Solar	Gas	% Solar		
213	0	0	0	0	0	24	0.00
214	6	0	0	0	0	20	0.00
215	9	59	59	0	100	22	2.67
216	7	92	92	0	100	22	4.12
217	2	47	47	0	100	23	2.04
218	0	0	0	0	0	14	0.00
219	0	0	0	0	0	24	0.00
220	3	0	0	0	0	23	0.00
221	3	0	0	0	0	5	0.00
222	2	0	0	0	0	23	0.00
223	0	0	0	0	0	23	0.00
224	0	0	0	0	0	24	0.00
225	0	0	0	0	0	24	0.00
226	0	0	0	0	0	22	0.00
227	6	16	16	0	100	23	0.71
228	0	36	36	0	100	24	1.52
229	0	0	0	0	0	21	0.00
230	7	-	-	-	-	--	--
231	8	35	35	0	100	23	1.51
232	0	17	17	0	100	24	0.69
233	0	0	0	0	0	23	0.00
234	0	0	0	0	0	23	0.00
235	0	0	0	0	0	24	0.00
236	0	0	0	0	0	20	0.00
237	2	-	-	-	-	--	--
238	0	0	0	0	0	14	0.00
239	0	0	0	0	0	24	0.00
240	4	0	0	0	0	22	0.00
241	9	19	19	0	100	21	0.86
242	9	75	75	0	100	21	3.51
243	2	51	51	0	100	22	2.34
TOTALS	79	447	447	0	100	623	0.72

Julian Date SEP	Solar Insolation $MJ/M^2/Day$ Cum,Horiz.	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance		
		Start °C	Finish °C	MJ Avail.	MJ Col.	%	MJ Avail	MJ Col.	%
244	18.3	56	63	387	152	39	387	120	31
245	13.8	57	62	308	64	21	308	99	16
246	21.7	58	68	476	206	43	476	156	33
247	21.6	59	70	476	193	41	476	135	28
248	3.7	62	69	78	0	0	78	1	1
249	20.0	64	74	448	193	43	448	134	30
250	---	--	--	---	---	--	---	---	--
251	19.3	66	78	440	192	44	440	123	28
252	1.7	76	75	36	3	7	36	2	5
253	15.0	67	69	347	74	21	0	0	0
254	0.0	66	66	0	0	0	0	0	0
255	17.5	62	66	0	0	0	418	169	40
256	16.8	57	61	0	0	0	405	112	28
257	12.4	54	54	0	0	0	301	124	41
258	19.2	53	58	0	0	0	0	0	0
259	17.8	55	59	0	0	0	438	199	45
260	4.6	56	56	0	0	0	113	6	5
261	19.8	49	55	0	0	0	0	0	0
262	16.0	50	56	0	0	0	0	0	0
263	1.2	52	52	0	0	0	0	0	0
264	0.0	38	38	0	0	0	0	0	0
265	18.7	31	41	0	0	0	490	300	61
266	17.0	36	46	0	0	0	0	0	0
267	7.2	42	42	0	0	0	0	0	0
268	14.2	37	41	0	0	0	384	108	28
269	17.5	37	47	0	0	0	0	0	0
270	---	--	--	---	---	--	---	---	--
271	---	--	--	---	---	--	---	---	--
272	---	--	--	---	---	--	---	---	--
273	---	--	--	---	---	--	---	---	--
TOTALS	13.4	53	58	2996	1076	36	5198	1737	33

System being modified; evacuated tube collectors being installed on ground array.

Julian Date SEP	Degree Days (°F)	House Heating Demand (MJ)				Time Interval Analysis	Avg Hourly Heating Demand MJ/Hour
		Total	Solar	Gas	% Solar		
244	0	0	0	0	0	24	0.00
245	1	0	0	0	0	23	0.00
246	0	0	0	0	0	18	0.00
247	1	0	0	0	0	24	0.00
248	0	0	0	0	0	12	0.00
249	0	0	0	0	0	22	0.00
250	1	-	-	-	-	--	--
251	2	0	0	0	0	21	0.00
252	0	0	0	0	0	6	0.00
253	0	0	0	0	0	17	0.00
254	2	0	0	0	0	3	0.00
255	7	0	0	0	0	21	0.00
256	12	68	68	0	100	24	2.83
257	10	51	51	0	100	14	3.64
258	1	16	16	0	100	23	0.70
259	0	0	0	0	0	23	0.00
260	11	0	0	0	0	19	0.00
261	6	61	61	0	100	23	2.65
262	22	118	118	0	100	22	5.36
263	26	92	92	0	100	10	9.20
264	24	47	47	0	100	6	7.83
265	15	142	142	0	100	24	5.92
266	7	93	93	0	100	23	4.04
267	7	71	71	0	100	23	3.07
268	10	403	403	0	100	21	19.19
269	6	66	66	0	100	22	3.00
270	6	-	-	-	-	--	--
271	6	-	-	-	-	--	--
272	7	-	-	-	-	--	--
273	13	-	-	-	-	--	--
TOTALS	201	1228	1228	0	100	468	2.62

System being modified; evacuated tube collectors being installed on ground array.

Julian Date OCT	Solar Insolation MJ/M^2/Day Cum, Horiz.	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance		
		Start °C	Finish °C	MJ Avail.	MJ Col.	%	MJ Avail.	MJ Col.	%
274	16.7	59	64	396	97	24	479	295	62
275	9.4	60	62	224	40	18	272	148	54
276	16.1	56	63	390	112	29	472	359	76
277	11.2	54	61	276	64	23	334	89	27
278	14.4	53	61	354	114	32	429	176	41
279	15.7	56	61	390	129	33	473	232	49
280	15.1	53	62	381	121	32	461	220	48
281	12.4	55	59	321	57	18	388	121	31
282	13.8	54	63	354	111	31	429	201	47
283	14.1	61	66	368	113	31	445	212	48
284	12.5	61	68	341	88	26	413	155	38
285	0.1	64	69	3	0	0	3	0	0
286	13.2	60	64	353	83	24	427	141	33
287	13.0	60	60	353	110	31	427	146	34
288	15.2	50	59	419	125	30	508	187	37
289	14.5	52	59	402	117	29	486	163	33
290	8.4	52	53	238	17	7	288	45	16
291	11.7	47	54	330	84	25	399	130	32
292	14.0	46	57	403	126	31	488	208	43
293	10.1	50	53	298	38	13	361	68	19
294	4.2	50	48	126	0	0	153	0	0
295	2.9	44	44	84	0	0	101	0	0
296	8.9	27	32	264	56	21	319	98	31
297	---	--	--	---	---	--	---	---	--
298	4.4	28	28	135	3	2	165	1	1
299	14.2	24	41	441	150	34	533	254	48
300	8.7	30	44	267	93	35	323	147	45
301	12.9	36	49	404	134	33	490	422	86
302	13.4	41	54	424	139	33	513	225	44
303	11.2	52	53	345	74	21	418	122	29
304	12.7	41	52	407	121	30	492	235	48
TOTALS	11.4	49	55	9491	2517	27	11490	4801	42

Julian Date OCT	Degree Days (°F)	House Heating Demand (MJ)				Time Interval Analysis	Avg Hourly Heating Demand MJ/Hour
		Total	Solar	Gas	% Solar		
274	3	34	34	0	100	24	1.42
275	13	0	0	0	0	17	0.00
276	20	81	81	0	100	24	3.35
277	14	112	112	0	100	22	5.09
278	23	147	147	0	100	22	6.60
279	21	140	140	0	100	23	6.17
280	14	119	119	0	100	24	4.96
281	11	78	78	0	100	24	3.23
282	9	31	31	0	100	22	1.36
283	11	67	67	0	100	20	3.33
284	1	16	16	0	100	24	0.66
285	16	0	0	0	0	11	0.00
286	25	173	173	0	100	23	7.48
287	21	126	126	0	100	20	6.29
288	14	118	118	0	100	23	5.08
289	16	104	104	0	100	23	4.52
290	7	82	82	0	100	23	3.59
291	21	77	77	0	100	22	3.52
292	15	107	107	0	100	24	4.46
293	10	83	83	0	100	24	3.47
294	12	75	75	0	100	24	3.11
295	28	245	245	0	100	17	14.23
296	28	253	193	60	76	24	10.53
297	16	--	--	-	--	--	--
298	32	319	284	35	89	24	13.28
299	27	197	82	115	41	24	8.22
300	19	173	173	0	100	20	8.78
301	16	130	130	0	100	24	5.38
302	15	128	128	0	100	24	5.32
303	26	145	145	0	100	21	7.07
304	24	188	188	0	100	23	8.19
TOTALS	528	3549	3339	210	94	664	5.34

Julian Date NOV	Solar Insolation $MJ/M^2/Day$ Cum, Horiz.	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance		
		Start °C	Finish °C	MJ Avail.	MJ Col.	%	MJ Avail.	MJ Col.	%
305	8.5	41	42	278	66	24	337	121	36
306	12.4	34	47	401	158	39	486	233	48
307	12.2	39	49	404	137	34	489	267	54
308	11.9	47	50	403	139	34	488	211	43
309	5.8	44	44	199	8	4	241	2	1
310	11.6	29	39	404	140	35	489	377	77
311	7.4	37	39	254	85	33	308	196	64
312	11.2	31	43	407	149	37	493	340	69
313	10.8	37	50	397	142	36	481	217	45
314	1.8	42	35	74	0	0	50	0	0
315	2.5	29	29	87	0	0	105	0	0
316	2.8	28	27	105	2	2	127	0	0
317	11.1	26	39	395	151	38	478	238	50
318	1.4	28	27	51	0	0	62	0	0
319	8.2	26	39	305	121	40	369	210	57
320	11.2	29	42	411	143	35	497	225	45
321	10.5	29	41	387	146	38	468	219	47
322	6.1	28	42	223	84	38	270	124	46
323	8.2	29	43	306	100	33	371	168	45
324	2.0	29	29	84	0	0	102	0	0
325	5.6	27	30	222	41	18	0	0	0
326	7.4	26	37	268	105	39	0	0	0
327	9.7	26	38	370	121	33	0	0	0
328	5.3	27	29	204	35	17	0	0	0
329	1.5	27	27	63	0	0	76	0	0
330	4.3	25	29	163	39	24	198	29	15
331	10.4	26	37	403	127	32	488	140	29
332	6.8	33	36	282	28	10	341	41	12
333	8.5	29	34	329	112	34	398	125	31
334	8.2	28	34	317	95	30	384	126	33
TOTALS	6.6	31	37	8197	2470	30	9635	3611	42

Julian Date NOV	Degree Days (^{o}F)	House Heating Demand (MJ)				Time Interval Analysis	Avg Hourly Heating Demand MJ/Hour
		Total	Solar	Gas	% Solar		
305	19	165	165	0	100	24	7.02
306	16	129	129	0	100	23	5.53
307	17	118	118	0	100	24	4.91
308	17	134	134	0	100	23	5.71
309	23	269	269	0	100	21	12.57
310	33	164	140	24	85	17	9.52
311	20	163	163	0	100	14	11.85
312	8	86	86	0	100	24	3.56
313	16	80	80	0	100	24	3.43
314	38	389	381	8	98	24	16.19
315	45	240	0	240	0	19	12.38
316	34	200	0	200	0	19	10.83
317	32	301	188	113	63	24	12.65
318	40	314	63	251	20	24	13.19
319	37	294	168	127	57	23	12.93
320	36	317	220	96	70	24	13.43
321	35	347	287	60	83	24	14.45
322	28	274	235	39	86	21	13.24
323	32	257	215	42	84	21	12.17
324	42	310	129	181	42	23	13.46
325	31	290	105	185	36	23	12.61
326	26	244	131	113	54	22	11.09
327	25	231	162	69	70	23	9.93
328	27	223	85	138	38	24	9.29
329	16	213	0	213	0	24	8.81
330	39	246	0	246	0	23	10.59
331	44	135	0	135	0	22	6.06
332	31	197	127	70	64	23	8.52
333	31	311	173	138	56	22	14.01
334	30	264	131	134	49	22	11.83
TOTALS	869	6907	4084	2824	59	669	10.33

Julian Date DEC	Solar Insolation MJ/M^2/Day Cum,Horiz.	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance		
		Start °C	Finish °C	MJ Avail.	MJ Col.	%	MJ Avail.	MJ Col.	%
335	7.3	28	32	297	71	24	359	99	28
336	3.4	27	27	134	0	0	162	0	0
337	9.3	28	29	371	100	27	449	20	5
338	8.7	27	34	344	118	34	416	133	32
339	2.8	29	28	126	0	0	152	0	0
340	1.6	27	27	70	0	0	85	0	0
341	6.0	24	24	239	0	0	289	0	0
342	10.1	23	24	408	43	11	494	0	0
343	9.6	26	28	395	106	27	478	9	2
344	4.5	26	27	187	26	14	226	1	0
345	9.4	26	34	399	133	33	484	132	27
346	0.0	31	31	0	0	0	0	0	0
347	8.0	28	30	330	0	0	400	121	30
348	8.3	28	41	325	121	37	394	234	59
349	1.9	28	38	84	21	25	102	59	58
350	1.6	29	36	71	13	18	86	39	45
351	6.2	28	29	268	23	9	324	52	16
352	6.7	27	32	274	75	27	332	170	51
353	3.0	26	32	120	36	30	145	79	55
354	6.0	27	35	251	81	32	304	196	64
355	3.0	28	35	140	30	21	170	56	33
356	7.0	28	38	295	110	37	358	202	57
357	3.6	29	28	176	0	0	214	0	0
468	9.1	27	37	390	138	35	472	216	46
359	4.8	28	32	194	44	22	235	67	29
360	9.6	28	35	422	129	31	510	231	45
361	7.0	28	38	296	95	32	358	187	52
362	4.2	28	38	170	60	35	205	112	55
363	4.3	29	28	165	0	0	200	0	0
364	6.3	27	28	260	6	2	315	37	12
365	7.8	26	30	306	58	19	371	127	34
TOTALS	5.4	27	31	7508	1636	22	9089	2579	28

Julian Date DEC	Degree Days (^{o}F)	House Heating Demand (MJ)				Time Interval Analysis	Avg Hourly Heating Demand MJ/Hour
		Total	Solar	Gas	% Solar		
335	31	279	146	134	52	24	11.64
336	57	257	0	257	0	16	16.36
337	52	349	0	349	0	23	15.13
338	27	301	136	166	45	22	13.44
339	37	249	0	249	0	20	12.27
340	55	340	0	340	0	20	16.69
341	65	398	0	398	0	22	17.75
342	68	442	0	442	0	23	19.18
343	48	371	0	371	0	23	16.00
344	41	256	0	256	0	22	11.71
345	38	244	78	167	32	19	12.95
346	29	69	8	61	12	7	9.29
347	44	315	47	268	15	24	13.14
348	24	245	145	100	59	21	11.44
349	30	231	206	25	89	18	12.94
350	43	313	179	134	57	18	17.38
351	34	308	45	263	15	24	12.81
352	19	157	67	89	43	21	7.45
353	26	197	137	60	70	18	11.13
354	42	301	134	167	45	22	13.93
355	33	288	107	180	37	20	14.71
356	36	296	183	114	62	22	13.29
357	45	319	13	306	4	23	13.86
358	37	361	181	180	50	24	15.06
359	40	317	68	249	21	23	13.68
360	45	418	207	211	50	24	17.31
361	26	303	185	118	61	22	13.89
362	29	287	200	88	69	20	14.39
363	46	342	31	311	9	22	15.70
364	60	408	0	408	0	23	17.72
365	59	432	43	389	10	24	17.91
TOTALS	1266	9393	2545	6848	27	655	14.34

Julian Date JAN	Solar Insolation MJ/M²/Day Cum,Horiz.	Storage Tank Temp Daily Start °C	Finish °C	Ground Array Performance MJ Avail.	MJ Col.	%	Roof Array Performance MJ Avail.	MJ Col.	%
1	2.9	27	27	113	4	3	137	1	1
2	8.3	24	32	335	117	35	405	177	40
3	7.9	28	36	328	119	36	396	224	56
4	9.1	28	35	357	115	32	432	212	49
5	7.6	28	32	300	60	20	363	143	40
6	8.8	28	33	352	95	27	426	203	48
7	8.8	28	33	348	89	26	421	192	46
8	1.4	28	37	78	7	8	94	18	19
9	8.2	28	33	327	67	21	395	159	40
10	6.0	28	30	238	29	12	288	53	19
11	6.7	27	29	1790	41	2	2167	77	4
12	4.4	27	28	179	3	1	217	22	10
13	8.5	27	30	330	77	23	400	111	28
14	8.9	27	33	348	87	25	421	182	43
15	0.6	28	33	37	0	0	44	0	0
16	8.3	29	38	317	86	27	383	182	48
17	8.2	29	33	310	71	23	376	144	38
18	6.1	28	29	249	16	7	301	52	17
19	4.1	27	28	170	5	3	206	20	10
20	10.3	27	35	387	95	24	469	204	43
21	10.0	28	39	377	101	27	456	210	46
22	4.5	29	31	166	25	15	201	50	25
23	10.5	30	32	393	97	25	476	107	23
24	8.6	28	37	312	92	29	378	173	46
25	5.7	28	30	206	25	12	250	46	18
26	6.0	27	27	217	3	1	263	1	0
27	11.6	24	33	417	106	26	504	217	43
28	0.6	29	29	28	0	0	34	0	0
29	4.1	28	27	137	0	0	166	0	0
30	11.4	27	30	398	88	22	481	108	22
31	11.6	27	35	404	116	29	489	228	47
TOTALS	7.0	27	32	9946	1834	18	12040	3518	29

Julian Date JAN	Degree Days (°F)	House Heating Demand (MJ)				Time Interval Analysis	Avg Hourly Heating Demand MJ/Hour
		Total	Solar	Gas	% Solar		
1	66	413	0	413	0	21	19.67
2	47	396	66	331	17	22	18.38
3	45	418	209	209	50	24	17.67
4	52	423	174	249	41	24	17.80
5	54	302	89	213	29	17	18.33
6	49	349	183	166	53	18	19.42
7	57	465	183	282	39	24	19.35
8	45	315	123	192	39	18	17.64
9	43	388	132	256	34	23	16.93
10	45	366	19	346	5	24	15.43
11	27	309	47	263	15	24	13.09
12	53	261	0	261	0	23	11.31
13	52	381	48	333	13	24	16.09
14	41	425	156	268	37	24	17.59
15	28	196	51	146	26	13	15.52
16	26	220	105	115	48	20	11.14
17	38	324	182	141	56	23	14.19
18	32	281	53	228	19	24	11.62
19	35	257	0	257	0	23	11.22
20	39	323	164	160	51	24	13.35
21	29	283	144	140	51	23	12.55
22	42	357	91	266	25	24	14.85
23	51	387	99	288	26	24	16.13
24	41	399	214	185	54	22	17.99
25	39	301	28	273	9	23	12.91
26	54	382	0	382	0	24	15.75
27	55	575	280	295	49	24	23.86
28	58	164	0	164	0	9	19.14
29	57	226	0	226	0	15	15.58
30	60	415	50	364	12	23	17.67
31	54	469	223	246	47	24	19.93
TOTALS	1404	10772	3111	7660	29	669	16.11

Julian Date FEB	Solar Insolation $MJ/M^2/Day$ Cum,Horiz.	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance		
		Start °C	Finish °C	MJ Avail.	MJ Col.	%	MJ Avail.	MJ Col.	%
32	10.2	28	33	356	85	24	431	176	41
33	10.7	28	37	355	107	30	430	220	51
34	12.2	28	38	414	126	30	501	248	49
35	10.5	28	37	345	94	27	418	203	49
36	12.1	28	39	401	120	30	486	269	55
37	10.1	29	37	320	89	28	387	189	49
38	10.5	28	34	349	78	22	422	162	38
39	12.3	28	38	400	111	28	484	258	53
40	11.7	29	41	382	111	29	463	244	53
41	12.6	28	41	393	134	34	476	222	47
42	10.8	33	41	346	95	27	418	173	41
43	4.8	31	35	157	19	12	190	31	16
44	12.9	26	41	392	126	32	475	267	56
45	14.1	37	50	551	127	23	668	260	39
46	4.9	48	48	146	20	14	177	47	26
47	5.7	31	26	170	0	0	206	0	0
48	12.4	19	28	376	126	33	455	254	56
49	14.0	21	33	419	140	33	507	282	56
50	11.0	23	33	327	101	31	396	202	51
51	14.3	24	38	415	140	34	502	280	56
52	11.0	27	34	312	72	23	377	178	47
53	14.0	24	37	423	125	30	511	254	50
54	10.8	26	31	300	71	24	363	141	39
55	7.8	21	26	223	41	19	270	95	35
56	12.5	19	27	343	105	31	416	209	50
57	9.1	20	25	266	56	21	322	154	48
58	5.7	18	18	155	1	1	187	0	0
59	15.1	14	24	402	152	38	487	251	52
TOTALS	9.7	26	34	9438	2570	27	11425	5268	46

Julian Date FEB	Degree Days (^{o}F)	House Heating Demand (MJ)				Time Interval Analysis	Avg Hourly Heating Demand MJ/Hour
		Total	Solar	Gas	% Solar		
32	45	364	156	208	43	22	16.56
33	41	325	190	135	58	20	15.90
34	43	424	254	170	60	24	17.67
35	49	402	256	146	64	24	17.00
36	43	367	187	180	51	23	16.10
37	42	210	111	99	53	16	13.54
38	35	334	176	158	53	22	14.90
39	42	358	223	134	62	24	14.91
40	32	275	191	184	69	21	12.82
41 *	28	215	215	0	100 *	23	9.20
42	21	272	272	0	100	22	12.14
43	23	306	306	0	100	22	14.07
44	13	139	139	0	100	23	5.95
45	12	28	28	0	100	24	1.16
46	34	152	152	0	100	14	11.10
47	47	392	392	0	100	24	16.33
48	37	309	309	0	100	24	12.87
49	35	284	284	0	100	24	11.83
50	28	220	220	0	100	23	9.54
51	29	182	182	0	100	20	9.05
52	34	293	293	0	100	23	12.50
53	33	242	242	0	100	23	10.45
54	38	313	313	0	100	22	14.21
55	36	269	269	0	100	22	12.08
56	35	274	274	0	100	23	11.90
57	21	183	183	0	100	23	7.81
58	34	157	157	0	100	20	7.74
59	33	220	220	0	100	23	9.40
TOTALS	943	7509	6194	1315	82	621	12.09

* LESS Experiment (ref Chapter 4) from Julian Day 41-59.

Julian Date MAR	Solar Insolation $MJ/M^2/Day$ Cum, Horiz.	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance		
		Start °C	Finish °C	MJ Avail.	MJ Col.	%	MJ Avail.	MJ Col.	%
60	12.1	18	28	320	99	31	388	208	54
61	4.8	21	21	127	7	5	153	25	16
62	13.6	21	30	353	108	31	428	186	43
63	16.5	27	39	423	133	31	513	334	65
64	16.1	29	42	409	130	32	495	337	68
65	15.3	29	29	384	109	28	465	275	59
66	14.2	30	43	349	119	34	423	270	64
67	12.4	33	40	303	65	22	367	154	42
68	8.3	28	29	200	10	5	242	17	7
69	17.8	28	39	430	140	33	521	283	54
70	15.6	29	44	377	128	34	456	279	61
71	0.2	33	43	4	0	0	5	0	0
72	6.3	32	33	149	27	18	181	58	32
73	0.0	36	36	0	0	0	0	0	0
74	17.4	28	41	399	130	33	482	274	57
75	13.8	29	38	311	85	27	377	193	51
76	13.0	27	34	293	77	26	354	161	46
77	12.1	28	30	268	50	19	324	87	27
78	9.6	26	32	211	53	25	255	93	37
79	1.0	26	26	22	0	0	27	0	0
80	2.1	24	24	45	0	1	54	0	0
81	7.9	23	23	168	0	0	204	0	0
2	18.2	21	22	384	37	10	465	0	0
83	20.4	23	28	425	146	34	515	49	10
84	11.2	29	36	233	93	40	282	100	35
85	6.8	27	27	139	1	1	168	1	1
86	17.0	25	34	344	118	34	416	213	51
87	17.3	29	37	347	114	33	420	232	55
88	14.4	31	41	283	83	29	343	178	52
89	13.9	29	33	272	59	22	329	126	38
90	6.9	26	27	135	13	10	164	27	16
TOTALS	10.9	27	33	8108	2133	26	9815	4161	42

Julian Date MAR	Degree Days (^{o}F)	House Heating Demand (MJ)				Time Interval Analysis	Avg Hourly Heating Demand MJ/Hour
		Total	Solar	Gas	% Solar		
60	24	207	207	0	100	23	8.88
61	32	282	107	175	38	24	11.95
62	44	294	50	244	17	23	12.56
63	40	351	200	151	57	24	14.61
64	35	272	190	82	70	23	11.72
65	26	183	183	0	100	17	10.93
66	23	88	88	0	100	16	5.53
67	29	300	300	0	100	24	12.50
68	40	248	67	180	27	23	10.89
69	37	305	171	134	56	24	12.66
70	24	193	146	47	76	23	8.32
71	23	196	196	0	100	12	15.88
72	29	171	171	0	100	12	14.29
73	30	69	69	0	100	5	14.48
74	25	232	198	34	85	23	10.06
75	22	256	256	0	100	23	11.04
76	20	265	265	0	100	24	11.02
77	33	235	141	94	60	23	10.32
78	25	272	113	160	41	24	11.35
79	34	199	0	199	0	21	9.40
80	29	198	0	198	0	23	8.58
81	37	230	0	230	0	23	10.15
82	37	206	0	206	0	24	8.57
83	29	154	0	154	0	22	7.18
84	24	719	719	0	100	13	56.40
85	32	255	66	188	26	24	10.61
86	23	206	99	108	48	24	8.59
87	17	156	156	0	100	23	6.95
88	23	227	227	0	100	20	11.33
89	25	304	304	0	100	24	12.66
90	30	220	61	159	28	24	9.11
TOTALS	911	7490	4749	2741	63	654	11.45

Julian Date APR	Solar Insolation MJ/M^2/Day Cum,Horiz.	Storage Temp Tank Daily		Ground Array Performance			Roof Array Performance		
		Start °C	Finish °C	MJ Avail.	MJ Col.	%	MJ Avail.	MJ Col.	%
91	10.8	25	25	208	2	1	251	0	0
92	16.9	23	28	323	45	14	391	87	22
93	---	--	--	---	---	--	---	---	--
94	---	--	--	---	---	--	---	---	--
95	---	--	--	---	---	--	---	---	--
96	---	--	--	---	---	--	---	---	--
97	---	--	--	---	---	--	---	---	--
98	---	--	--	---	---	--	---	---	--
99	0.8	40	40	12	0	0	15	0	0
100	7.4	29	29	129	7	5	157	10	6
101	1.3	29	28	21	4	20	26	0	0
102	14.3	27	29	249	51	20	301	17	6
103	19.2	27	34	327	100	30	396	10	28
104	23.4	30	39	393	126	32	476	33	49
105	21.0	31	38	348	-77	-22	421	12	50
106	7.6	31	36	118	0	0	143	41	29
107	17.7	30	33	289	11	4	349	08	31
108	15.1	28	33	243	-1	0	295	26	43
109	---	--	--	---	---	--	---	---	--
110	---	--	--	---	---	--	---	---	--
111	---	--	--	---	---	--	---	---	--
112	---	--	--	---	---	--	---	---	--
113	---	--	--	---	---	--	---	---	--
114	---	--	--	---	---	--	---	---	--
115	---	--	--	---	---	--	---	---	--
116	---	--	--	---	---	--	---	---	--
117	---	--	--	---	---	--	---	---	--
118	---	--	--	---	---	--	---	---	--
119	---	--	--	---	---	--	---	---	--
120	---	--	--	---	---	--	---	---	--
TOTALS	13.0	29	32	2660	267	10	3220	45	29

Instrumentation and data recording system malfunctioned most of month.

Julian Date APR	Degree Days (^{o}F)	House Heating Demand (MJ)				Time Interval Analysis	Avg Hourly Heating Demand MJ/Hour
		Total	Solar	Gas	% Solar		
91	43	242	0	242	0	24	10.05
92	37	149	0	149	0	17	8.65
93	39	--	--	--	--	--	--
94	32	--	--	--	--	--	--
95	22	--	--	--	--	--	--
96	25	--	--	--	--	--	--
97	18	--	--	--	--	--	--
98	22	--	--	--	--	--	--
99	21	75	75	0	100	7	10.91
100	26	232	140	91	61	24	9.59
101	36	89	0	89	0	9	10.23
102	34	208	0	208	0	24	8.62
103	24	1191	1083	108	91	22	53.55
104	16	1238	1219	18	99	24	51.57
105	10	109	109	0	100	23	4.69
106	10	107	107	0	100	24	4.51
107	9	96	96	0	100	24	3.99
108	10	96	96	0	100	14	6.80
109	13	--	--	--	--	--	--
110	20	--	--	--	--	--	--
111	17	--	--	--	--	--	--
112	11	--	--	--	--	--	--
113	9	--	--	--	--	--	--
114	6	--	--	--	--	--	--
115	22	--	--	--	--	--	--
116	18	--	--	--	--	--	--
117	25	--	--	--	--	--	--
118	22	--	--	--	--	--	--
119	22	--	--	--	--	--	--
120	21	--	--	--	--	--	--
TOTALS	640	3832	2925	907	76	237	16.20

Total for May 78 - Apr 79 $\frac{30616 \text{ Solar}}{55192 \text{ Total}} = 55.5\%$

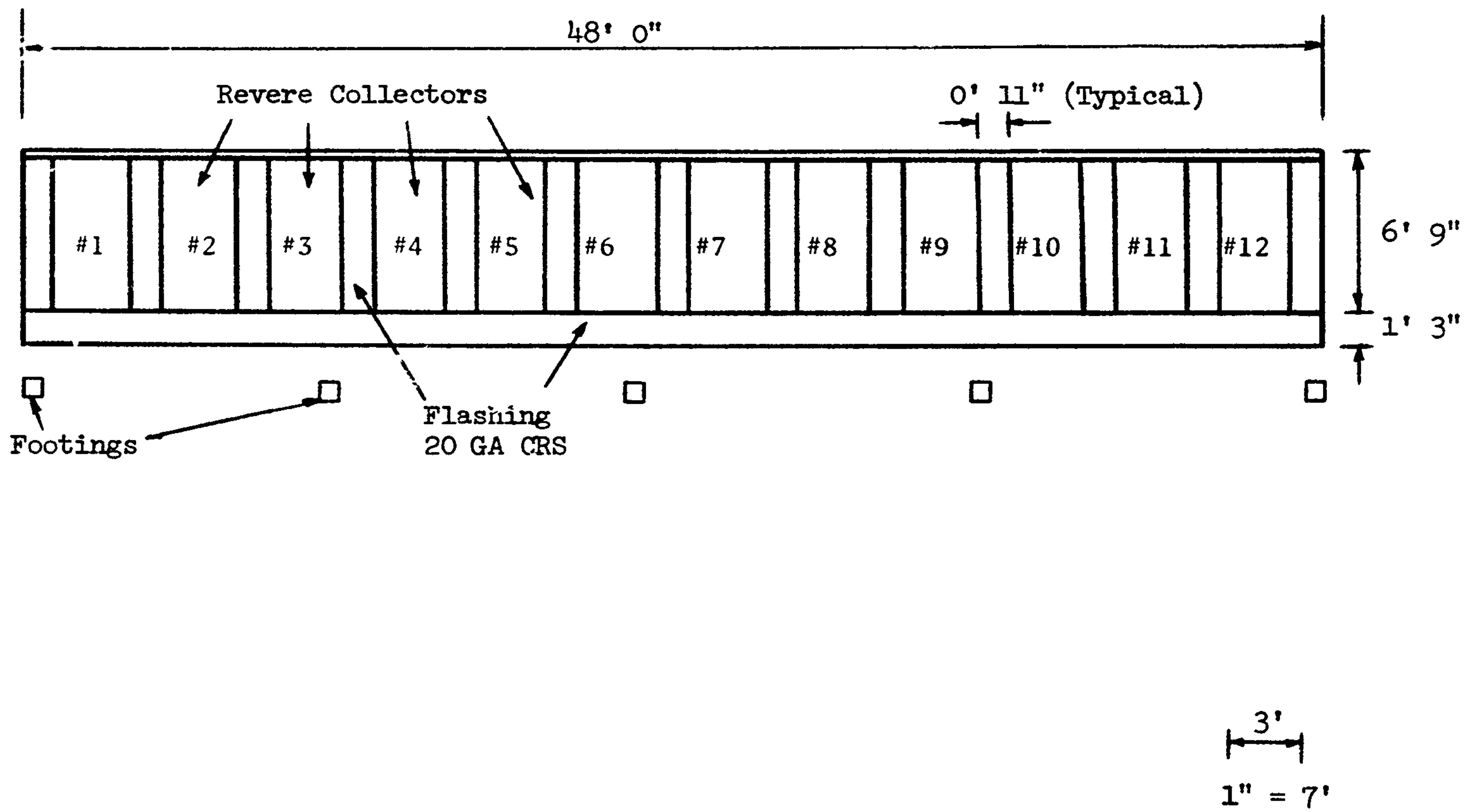
Instrumentation and data recording system malfunctioned most of month.

APPENDIX B

GROUND ARRAY FINAL CONFIGURATION

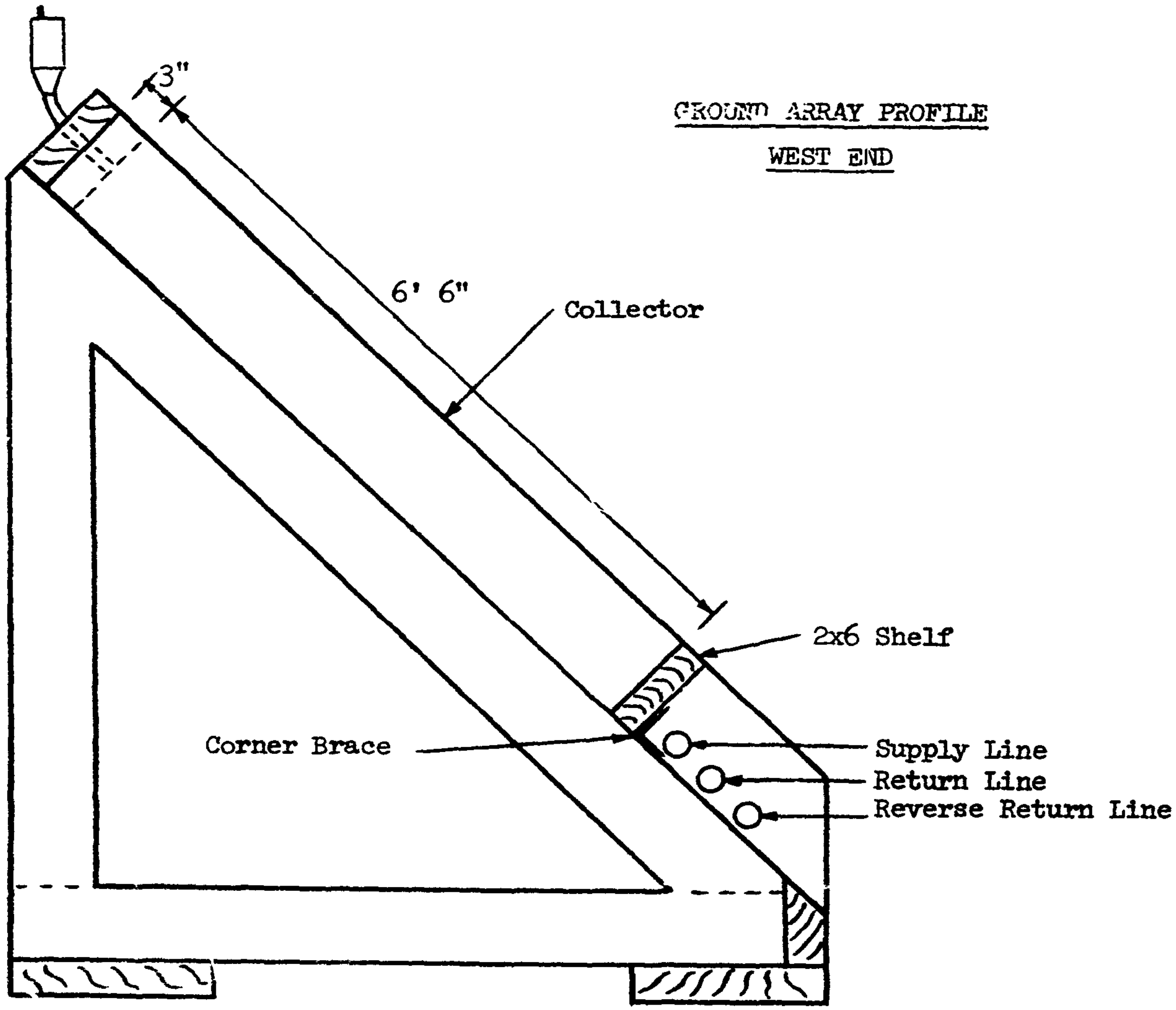
GROUND ARRAY MODIFICATION

GENERAL PLAN



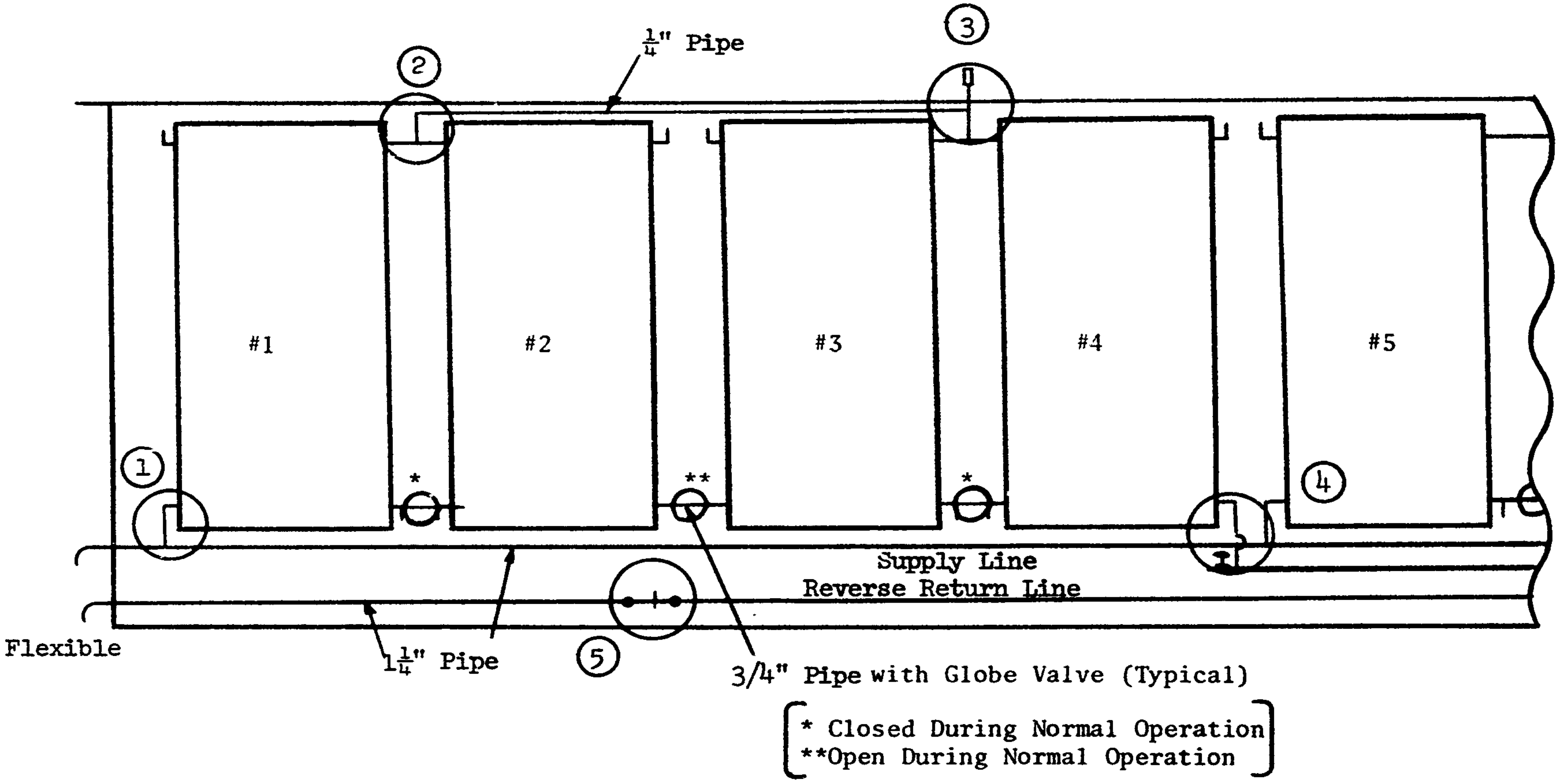
GROUND ARRAY PROFILE

WEST END



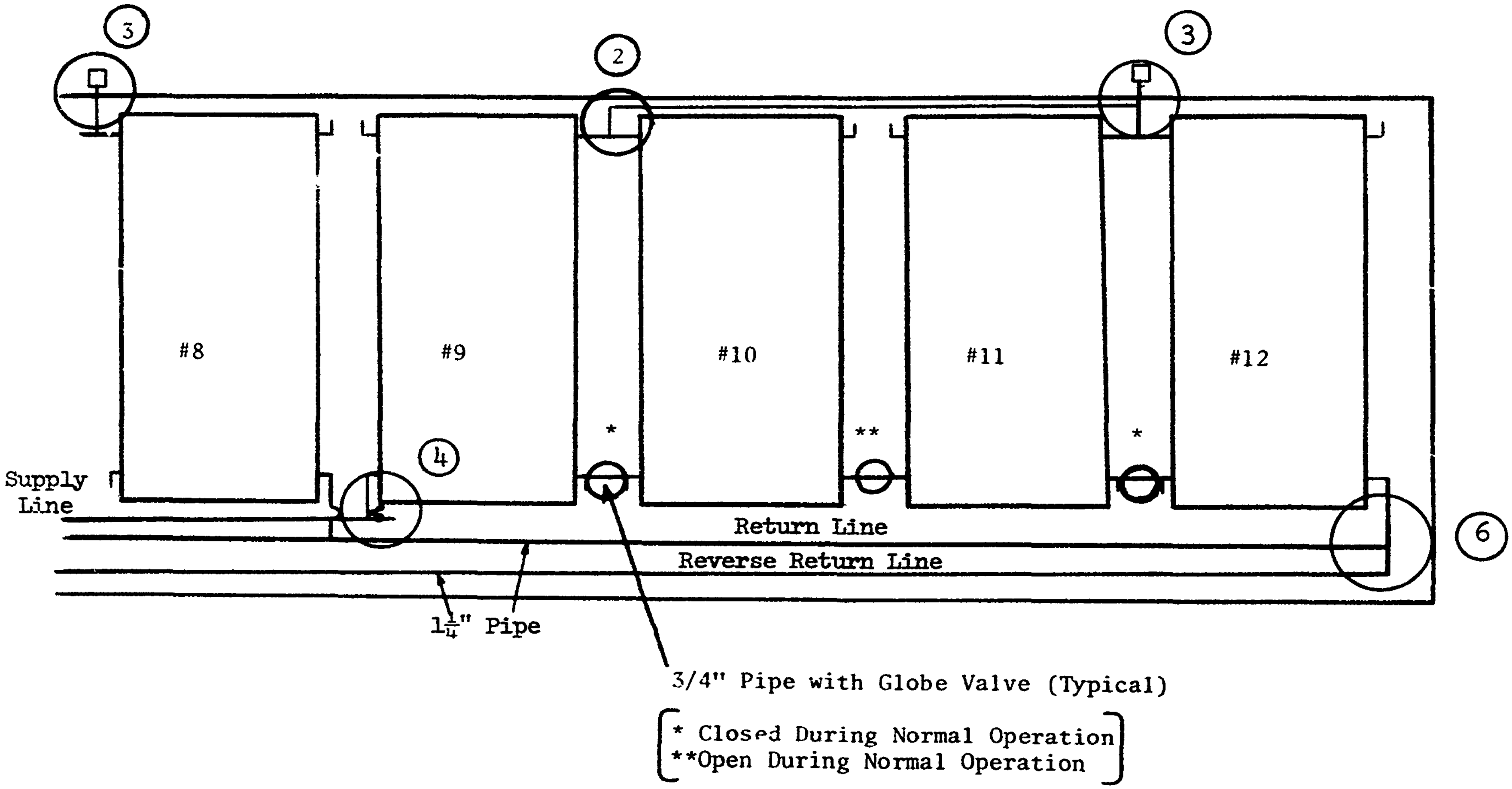
GROUND ARRAY PLUMBING PLAN

WEST END

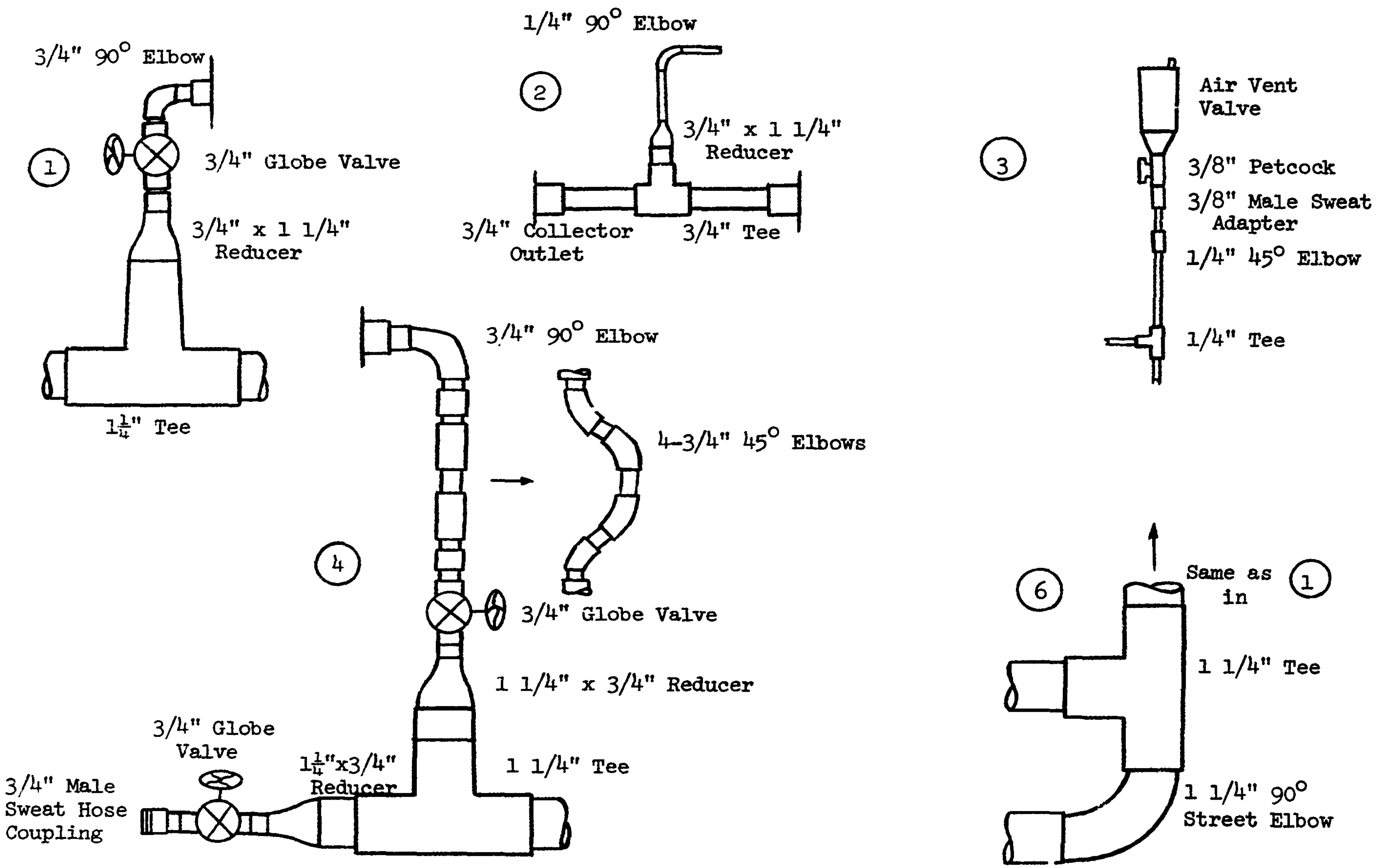


GROUND ARRAY PLUMBING PLAN

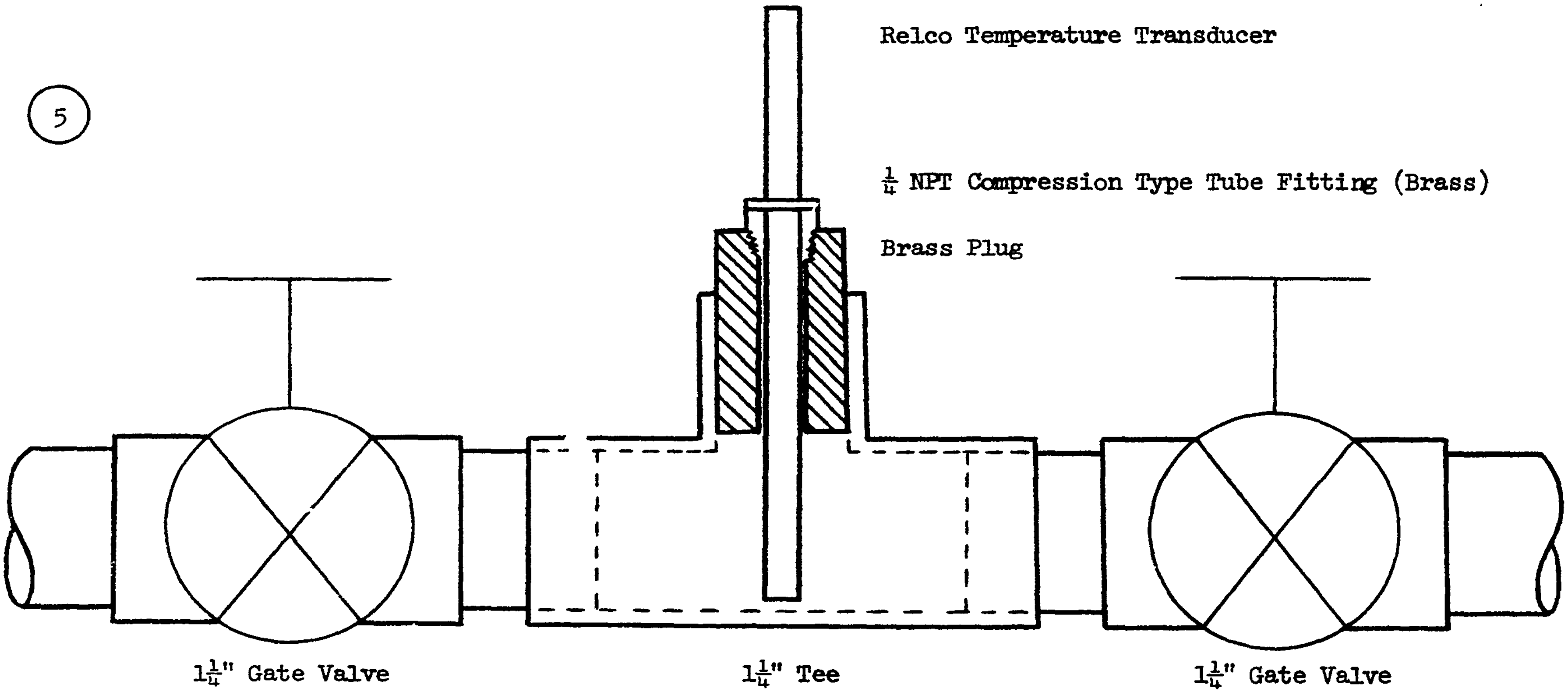
EAST END



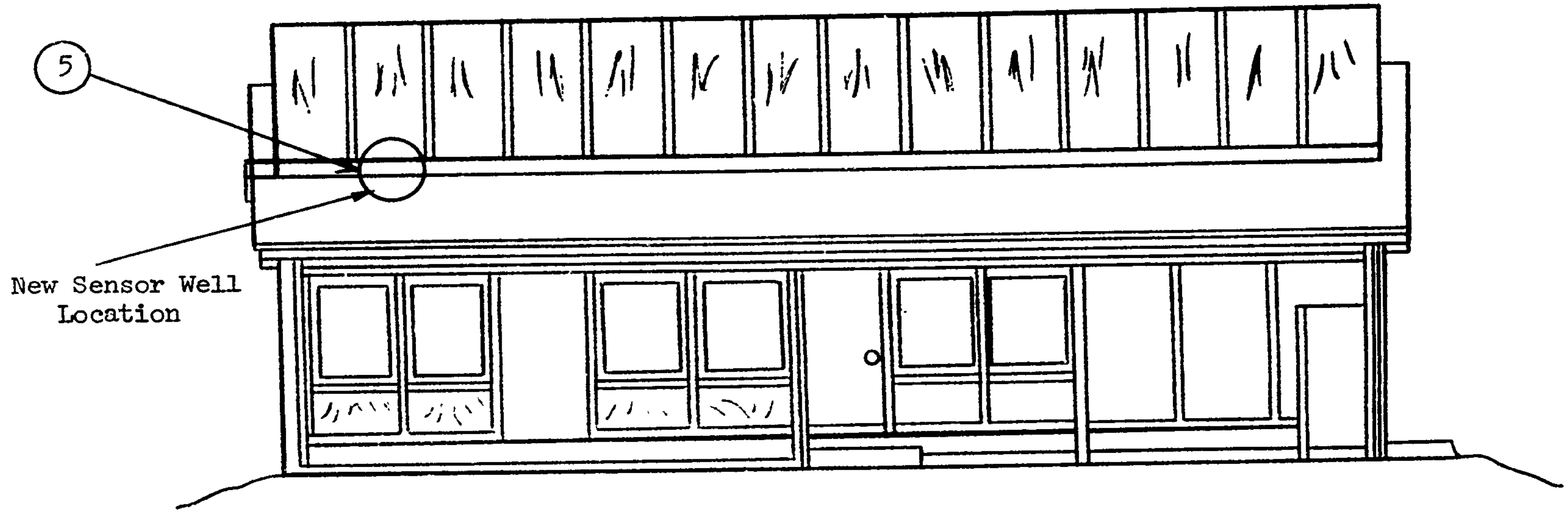
PLUMBING DETAILS



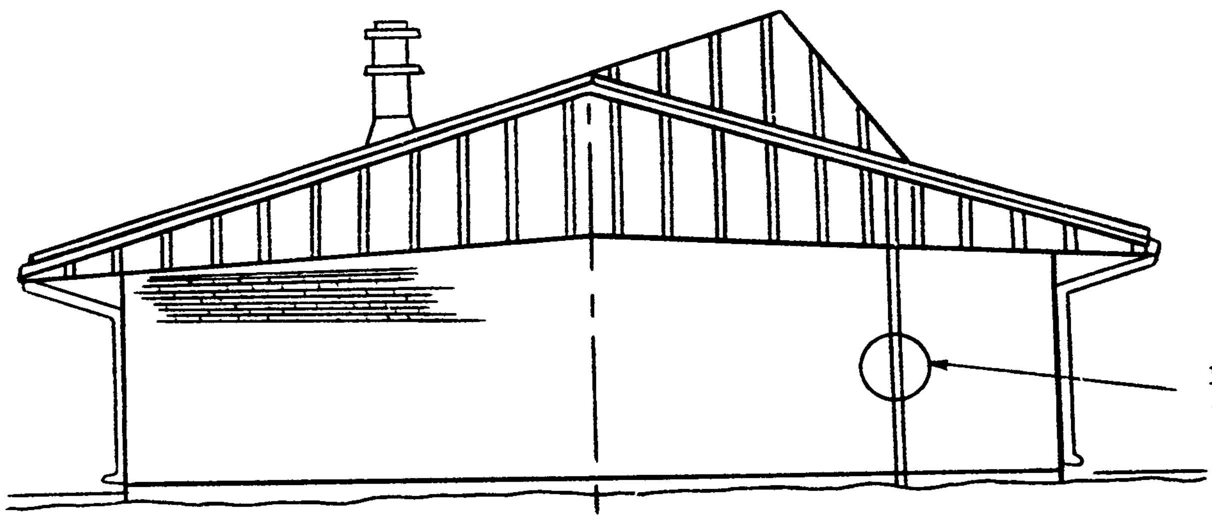
PLUMBING DETAILS (Continued)



ROOF ARRAY MODIFICATION



South Elevation



West Elevation

APPENDIX C

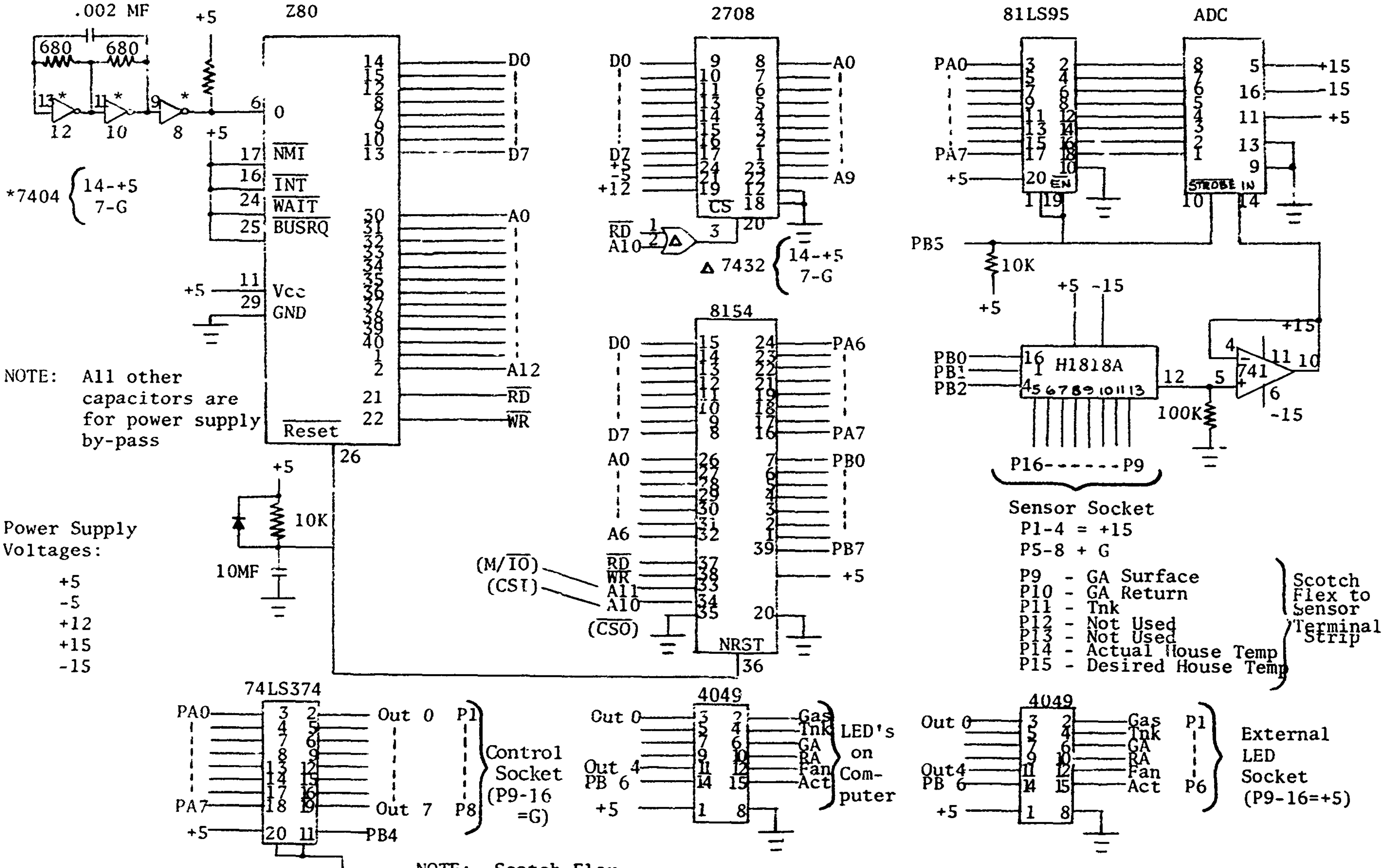
SOLAR CONTROLLER WIRING DIAGRAM

AND CONTROL PROGRAM

APPENDIX C

SOLAR CONTROLLER WIRING DIAGRAM AND CONTROL PROGRAM

SOLAR CONTROLLER WIRING DIAGRAM



NOTE: All other capacitors are for power supply by-pass

Power Supply Voltages:

+5
-5
+12
+15
-15

NOTE: Scotch Flex from control socket to crydom switches

NOTE: Scotch Flex from ext. LED socket to front panel LEDs.

Final Solar Control Program

```
        ORG     0C0C0H          ;TEMPORARY STORAGE AREA
T0:     DB      0               ;TEMP ON GA COLLECTOR SURFACE
T1:     DB      0               ;WATER TEMP OUT OF GA
T2:     DB      0               ;STORAGE TANK TEMP
T3:     DB      0               ;NOT USED
T4:     DB      0               ;NOT USED
T5:     DB      0               ;LIVING AREA TEMP
T6:     DB      0               ;LIVING AREA REQ TEMP
T7:     DB      0               ;NOT USED
FOLA:   DB      0               ;FAN ON DELAY WORD
FOFD:   DB      0               ;FAN OFF DELAY WORD
PUMP:   DB      0               ;CONTROL WORD
RADLA:  DB      0               ;RA PUMP DELAY WORD
GADLA:  DB      0               ;GA PUMP DELAY WORD
;--------------------------------------------------
;                               NEXT NEW LOC:0C0DH
;
;
;
        ORG     0C00H           ;START PROGRAM AREA
START:  LXI     SP,0C80H        ;SET STACK TO CC80
        MVI     A,0             ;
        STA     PUMP            ;INITIALIZE PUMP CONTROL
        STA     FOLA            ;INITIALIZE FAN ON DELAY
        STA     FOFD            ;INITIALIZE FAN OFF DELAY
        STA     RADLA           ;INITIALIZE RA DELAY
        STA     GADLA           ;INITIALIZE GA DELAY
SCHED:  LDA     PUMP            ;SEND CONTROL WORD
        CALL    CONTROL         ;
        CALL    SHCNTL          ;CONTROL THE HOUSE
        MVI     D,4             ;ROUTINE TO DELAY 1 SEC
AGAIN:  MVI     E,0FFH          ;LOAD E WITH 255
        CALL    DMS             ;DELAY A QUARTER SEC
        DCR     D               ;DO THIS 3 MORE TIMES
        JNZ     AGAIN           ;
        CALL    BLINK           ;BLINK ACTIVITY LED
        JMP     SCHED           ;DO IT ALL OVER AGAIN
; SHCNTL GATHERS DATA AND CONTROLS THE HOUSE
;
SHCNTL: CALL    READ            ;COLLECT DATA
        CALL    GNDARRAY        ;CONTROL GA
        CALL    HEATCOIL        ;SEE IF HEATING NEEDED
        RET
;
;
;GROUND ARRAY CONTROL ROUTINE - FOR GA AND RA CONTROL
;
GNDARRAY: LDA   GADLA           ;GET CONTROL WORD
        ANA     A               ;SET FLAGS
        JZ      GACNTRL         ;IF TIME UP,CONTROL GA
        DCR     A               ;COUNT DOWN
        JNZ     GALEV           ;IF TIMING NOT UP,LEAVE
        STA     GADLA           ;SAVE CONTROL WORD
GACNTRL: MVI    A,169           ;MAX TEMP TO LET COLLECTOR COOK TO
        LXI     H,T0            ;GET SURFACE TEMP
        CMP     M               ;TC>169?
        JNC     OPGA            ;NO CHECK WITH TANK TEMP
        LDA     PUMP            ;YES GET CONTROL WORD
        ORI     0CH             ;OUTPUT WORD FOR PUMPS ON
        CALL    CONTROL         ;TURN PUMPS ON
        STA     PUMP            ;SAVE CONTROL WORD
        MVI     A,50            ;SET TIMING
GALEV:  STA     GADLA           ;SAVE CONTROL WORD
        RET
OPGA:   LDA     T2              ;GET TANK TEMP
```

```
        ADI     19          ;A=T2+19
        LXI     H,T0        ;GET SURFACE TEMP
        CMP     M           ;T0>T2+19?
        JNC     ONE         ;NO CHECK WATER TEMP
        LDA     FUMP        ;YES GET CONTROL WORD
        ORI     0CH         ;OUTPUT PUMPS ON CONTROL WORD
        CALL    CONTROL     ;TURN PUMPS ON
        STA     FUMP        ;SAVE CONTROL WORD
        MVI     A,5C        ;SET TIMING
        STA     CADLA       ;SAVE CONTROL WORD
        RET
ONE:    PUSH    PSW         ;CHECK TO SEE IF PUMP ON
        LDA     FUMP        ;GET CONTROL WORD
        ANI     4           ;IS PUMP ON?
        JZ      GEXIT       ;NO LEAVE
        POP     PSW         ;YES CHECK OTHER TEMPS
TWO:    LDA     T2          ;GET TANK TEMP
        ADI     4           ;A=T2+4
        LXI     H,T1        ;GET EXIT TEMP(T1)
        CMP     M           ;T1>T2+4?
        JNC     THREE       ;NO TURN OFF PUMPS
        RET                 ;YES RETURN
THREE:  LDA     FUMP        ;GET CONTROL WORD
        ANI     0F3H        ;OUTPUT PUMPS OFF WORD
        CALL    CONTROL     ;TURN PUMPS OFF
        STA     FUMP        ;SAVE CONTROL WORD
        RET
GEXIT:  POP     PSW         ;LEAVE
        RET
;
;HEATCOIL CHECKS TO SEE IF HEAT IS REQUIRED AND IF SO ,DECIDES
;WHEATHER TO HEAT BY SOLAR OR GAS
;
HEATCOIL: LDA   FUMP        ;SEE IF PUMP IS ON IF SO SEE IF FAN
        ANI     2           ;SHOULD BE TURNED ON.
        CNZ     FANON       ;
        LDA     T5          ;GET LIVING AREA TEMP
        ADI     1           ;A=T5+1
        LXI     H,T6        ;GET LIVING AREA REQ TEMP
        CMP     M           ;T6>T5+1?
        JNC     WARM        ;NO CHECK ON THE HEATING
COLD:   CALL    SORGAS      ;YES THEN HEAT BY SOLAR OF GAS
        RET
WARM:   CALL    SH          ;CHECK TO STILL HEATING
        RET
SORGAS: LDA     T2          ;GET TANK TEMP
        CPI     66          ;T2>66?
        JNC     TANKH       ;YES HEAT BY TANK
        CALL    GAS         ;NO HEAT BY GAS
        RET
TANKH:  CALL    PUMPON      ;ROUTINE TO TURN PUMP ON
        RET
GAS:    LDA     FUMP        ;GET CONTROL WORD
        ORI     1           ;OUTPUT GAS ON WORD
        ANI     0DH         ;MAKE SURE TO TURN OFF TAK&FAN
        CALL    CONTROL     ;TUN GAS ON
        STA     FUMP        ;SAVE CONTROL WORD
        RET
PUMPON: LDA     FUMP        ;GET CONTROL WORD
        ANI     2           ;IS PUMP ON?
        JNZ     PISON       ;YES RETURN
        LDA     FUMP        ;NO GET CONTROL WORD
        ORI     2           ;OUTPUT PUMP ON WORD
        CALL    CONTROL     ;TURN PUMP ON
        STA     FUMP        ;SAVE CONTROL WORD
        MVI     A,5C        ;SET TIMING FOR FAN ON
        STA     FDLA        ;STORE IN FAN ON DELAY
PISON:  RET
FANON:  LDA     FDLA        ;GET CONTROL WORD
        ANA     A           ;SET FLAGS
        JZ      EXIT        ;IF FAN ON LEAVE
```

```
         DCR     A          ;START COUNTING DOWN
         JNZ     NOYET      ;IF TIME NOT UP LEAVE
         STA     FDLA       ;SAVE CONTROL WORD
         LDA     FUMP       ;GET CONTROL WORD
         ORI     01CH       ;OUTPUT FAN ON WORD
         CALL    CONTROL    ;TURN FAN ON
         STA     FUMP       ;SAVE CONTROL WORD
         RET
NOYET:   STA     FDLA       ;SAVE/COUNT
EXIT:    RET
SH:      CALL    FCFF       ;SEE IF FAN SHOULD BE TURNED OFF
         LDA     T6         ;GET REQ TEMP
         ACI     1          ;A=T6+1
         LXI     H,T5       ;GET LIVING AREA TEMP
         CMP     M          ;T5>T6+1?
         RNC                ;NO STILL HEATING
         CALL    POFF       ;YES TURN PUMP OR GAS OFF
         RET
POFF:    LDA     FUMP       ;GET CONTROL WORD
         ANI     2          ;IS PUMP ON?
         JZ      GASOFF     ;NO CHECK GAS
         LDA     FUMP       ;GET CONTROL WORD
         ANI     0FCH       ;OUTPUT PUMP OFF WORD
         CALL    CONTROL    ;TURN PUMP OFF
         STA     FUMP       ;SAVE CONTROL WORD
         MVI     A,50       ;SET FAN OFF TIMING
         STA     FOFD       ;STORE IT IN FAN OFF DELAY
         RET
GASOFF:  LDA     FUMP       ;GET CONTROL WORD
         ANI     1          ;IS GAS ON?
         JZ      LEV        ;NO RETURN
         LDA     FUMP       ;GET CONTROL WORD
         ANI     0FEH       ;OUTPUT GAS OFF WORD
         CALL    CONTROL    ;TURN GAS OFF
         STA     FUMP       ;SAVE CONTROL WORD
LEV:     RET
FCFF:    LDA     FUMP       ;GET CONTROL WORD
         ANI     2          ;SEE IF PUMP IS ON IF SO WE LEAVE
         RNZ                ;THE FAN ALONE
         LDA     FOFD       ;GET THE DELAY WORD
         ANA     A          ;SET FLAGS
         JZ      FEXIT      ;IF FAN OFF LEAVE
         DCR     A          ;START COUNTING DOWN
         JNZ     WAIT       ;IF NOT TIME LEAVE
         STA     FOFD       ;SAVE CONTROL WORD
         LDA     FUMP       ;GET CONTROL WORD
         ANI     0FFH       ;OUTPUT FAN OFF WORD
         CALL    CONTROL    ;TURN FAN OFF
         STA     FUMP       ;SAVE CONTROL WORD
         RET
WAIT:    STA     FCFD       ;SAVE COUNT
FEXIT:   RET

         ;CONTROL OUTPUTS CONTENTS OF ACC TO
         ;CONTROL PORT--ACC UNAFFECTED
         ;
CONTROL: PUSH    PSW        ;SAVE VALUE TO BE OUTPUT
         MVI     A,7FH      ;SET PORT B TO OUTPUT
         STA     C41DH      ;MAKE SURE BUFFER IS OFF
         STA     C423H      ;SET PORT B TO OUTPUT
         MVI     A,CFFH     ;
         STA     C422H      ;SET PORT A TO OUTPUT
         POP     PSW        ;GET VALUE BACK
         STA     C420H      ;WRITE IT OUT TO THE LATCH
         STA     C40CH      ;STROBE THE LATCH
         STA     C41CH      ;
         RET
         ;
         ;D8MS=DELAYS 8 MILLISECONDS,B AND C AFFECTED
         ;
D8MS:    MVI     C,1PH      ;WAIT FOR 8 MS
```

```
DIMS:   DCR     C               ;ONLY BC PAIR AFFECTED
        JNZ     DIMS            ;
        DCR     B
        JNZ     DIMS            ;
        RET
;
;BLINK-FLASHES ACTIVITY LED EACH TIME CALLED
BLINK:  PUSH    PSW             ;SAVE A
        LDA     C421H           ;GET PORT B DATA
        XRI     40H             ;COMPLEMENT BIT 6
        STA     C421H           ;COMPLEMENT LED
        POP     PSW             ;
        RET
;
;SENSE-READ SW INPUT,SETS ZERO FLAG
SENSE:  LDA     C4CFH           ;GET BIT 7 ONLY
        ORA     A               ;SET FLAG
        RET
;
;THIS ROUTINE READS ALL OF THE SENSORS AND STORES
;THEM IN RAM STARTING AT DC00H-DC07H. IN THE
;PROPER ORDER-NO REG ARE AFFECTED
READ:   PUSH    PSW             ;SAVE EVERYTING
        PUSH    B               ;
        PUSH    H               ;
        LXI     H,DC07H         ;READ ALL SENSORS AND STORE
        XRA     A               ;CLEAR A
        STA     C422H           ;SET PORT A TO INPUT
        MVI     A,7FH           ;SET PORT B TO OUTPUT
        STA     C423H           ;EXCEPT PB7
READ1:  LDA     C421H           ;GET PORT B STATUS BITS
        ANI     0F8H            ;SAVE EVERYTHING EXCEPT
        ORA     L               ;LOW 3 BITS, MERGE CHANNEL
        ORI     30H             ;NUMBER,MAKE SURE THE LATCH
        STA     C421H           ;IS RESET AND BUFFER IS OFF
        MVI     B,01            ;WAIT 1 MS FOR 741
        CALL    DIMS            ;TO SETTLE
        STA     C41CH           ;STROBE PB5
        MVI     B,01            ;WAIT 1 MS FOR ADC
        CALL    DIMS            ;TO GET DONE
        LDA     C420H           ;GET DATA
        STA     C41CH           ;RESET STROBE AND BUFFER
        MOV     M,A             ;STORE THE RESULT IN RAM
        DCR     L               ;GO TO NEXT CHANNEL
        JP      READ1           ;NOT DONE YET
        POP     H               ;ALL DONE LETS LEAVE
        POP     B
        POP     PSW             ;
        RET
        END
```

APPENDIX D

SOLAR HOUSE OPERATION AND

MAINTENANCE MANUAL

TABLE OF CONTENTS

LIST OF FIGURES

1.0 Purpose

This User's Manual provides guidance for the routine maintenance and repair (M&R) of those mechanical systems peculiar to the USAF Academy's solar home, Quarters 4518-I.

2.0 Overview of House Operation

Figure 1 is a schematic depicting the locations of the solar mechanical systems. The fundamental operation of these systems involves collection of the sun's energy as heat. The sun heats up solar collector panels located on the roof and on the ground behind the house. A water/ethylene glycol mixture is circulated by pumps (Pump #1 is the ground array pump; Pump #2 is the roof array pump) through the solar panels during sunny periods and becomes hot. The heated fluid then passes through submerged heat exchangers in an underground concrete storage tank which is filled with water (no ethylene glycol is in the storage tank water). This tank is near the northwest corner of the house.

Within the tank, the heat is transferred to the water via the submerged heat exchangers. When heat is required in the house, the storage tank water is pumped (by Pump #4) into the house and through a water-to-air coil near the furnace in the return air plenum. Air is blown across this coil by the furnace fan. The air, heated in this manner, is distributed into the house by the normal furnace duct system. If the temperature of the solar heated water in the storage tank is not high enough to heat the home, the gas furnace will come on as a backup.

3.0 Ground Collector Array

Figure 2 is a schematic of the ground collector array. The piping network for these panels has been designed to facilitate any routine maintenance or repair that may be required.

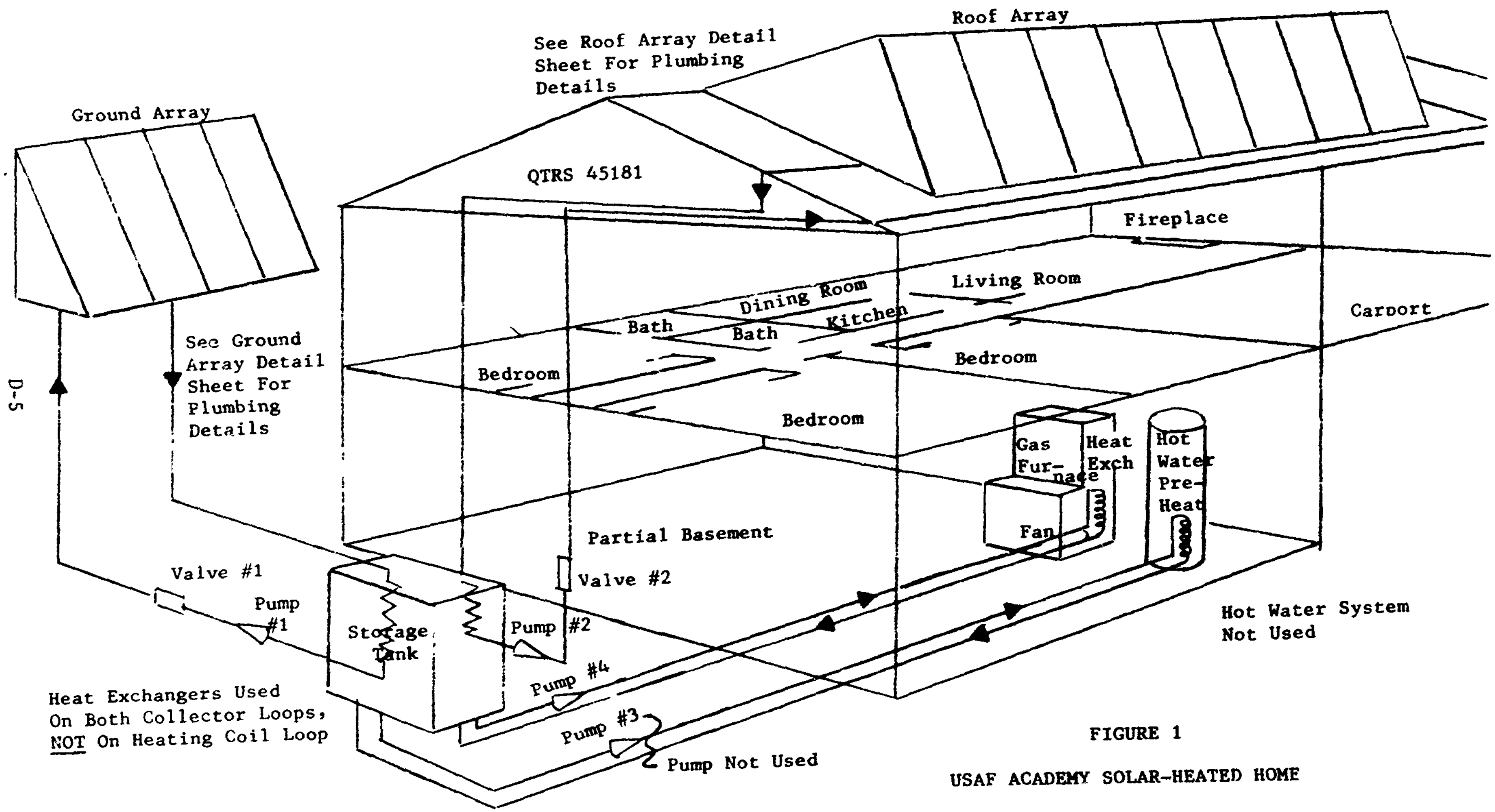


FIGURE 1

USAF ACADEMY SOLAR-HEATED HOME

3.1 Maintenance and Operation of Ground Solar Panels

Twelve Revere Copper Corporation collector panels make up the ground array. (Manufacturer's specification data is Appendix 1.) These collectors are connected in three parallel groups of four each. In order to accomplish replacement or repair of an individual collector, the water/antifreeze mixture must first be drained from the applicable group of four panels. Figure 3 outlines proper valve positions (opened or closed) for draining, and positions for normal operation.

3.2 Ground Array Fluid Temperature Sensor

The temperature sensor located on the reverse return line (see Figure 2) can be replaced if necessary. Close valves 14 and 15 to isolate the section of pipe containing the sensor. Replace the sensor, then open valves 14 and 15 to restore normal flow. (Manufacturer's sensor specification information is Appendix 2.)

4.0 Roof Collector Array

The plumbing system for the roof array was also designed for ease of maintenance. The roof array is very similar to the ground array with the exception of: (1) The roof array has 14 Revere collector panels instead of 12, (2) the roof array has no reverse return line. Figure 4 shows details of the roof array plumbing system.

4.1 Maintenance and Operation of Roof Solar Panels

Unlike the ground array, each solar collector panel on the roof can be drained separately for maintenance or replacement. Figure 4 shows the numbering of valves in the roof array system, and Figure 5 shows which valves to open or close to repair or replace any particular collector panel.

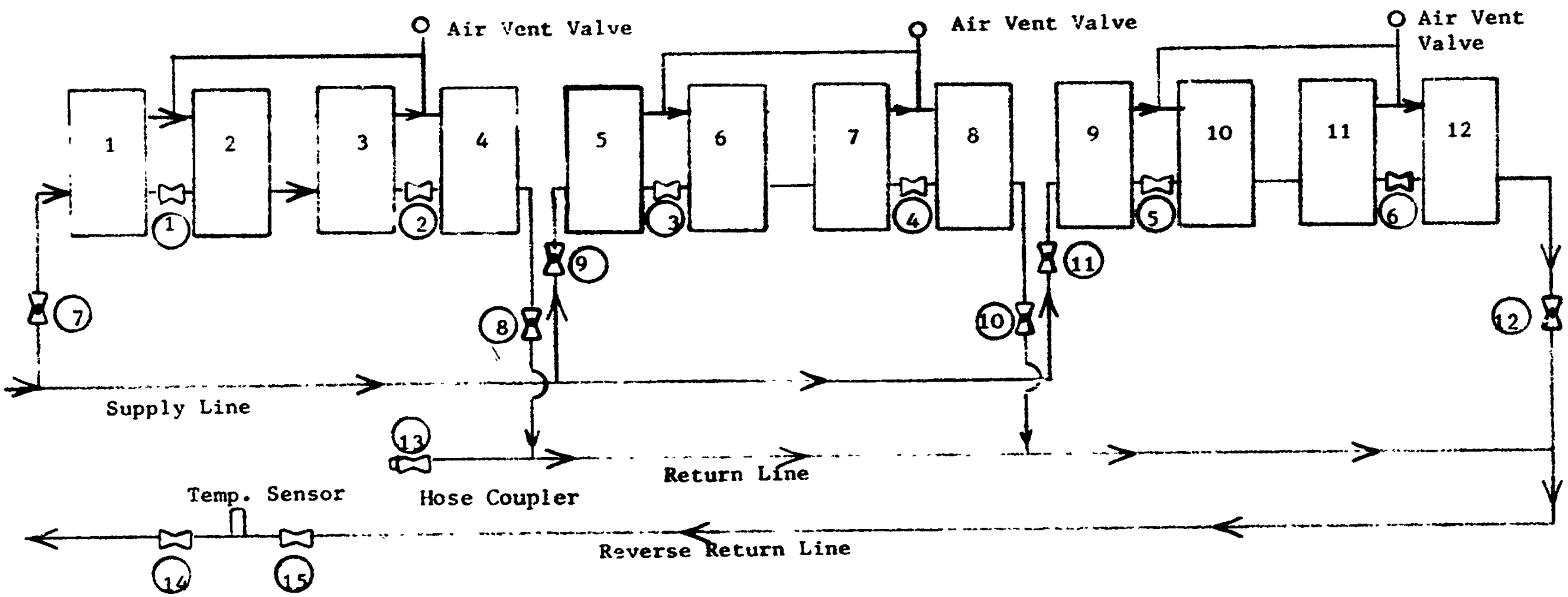


FIGURE 2

GROUND ARRAY SCHEMATIC WITH VALVE NUMBERING SYSTEM

Collector Numbers	To Drain for Maintenance or Repair		For Normal Operation of System	
	Close Valves	Open Valves	Closed Valves	Opened Valves
Entire Array (All Collectors Simultaneously)	7, 9, 11	1, 2, 3, 4, 5, 6, 8, 10, 12, 13	1, 2, 3, 4, 5, 6, 13	7, 8, 10, 12, 14, 15
All instructions which follow assume starting with the complete array operating normally.				
1 thru 4	7, 10, 12	1, 2, 13	1, 2, 13	7, 8
5 thru 8	9, 8, 12	3, 4, 13	3, 4, 13	9, 10
9 thru 12	11, 8, 10	5, 6, 13	5, 6, 13	11, 12

NOTE: To insure complete draining of collectors be sure to break the vacuum by loosening or removing the air vent valves.

FIGURE 3. PROCEDURES FOR DRAINING AND REFILLING GROUND ARRAY FOR MAINTENANCE OR REPAIR

4.2 Roof Array Temperature Sensors

Absorber plate and return fluid sensors are installed but are not used for control of the system. See paragraphs 10, III, B, 1, c and d (page 18) for further information regarding these back-up sensors.

5.0 Maintenance of Proper Water/Ethylene Glycol Mixture in Collectors

The fluid within the solar collector panels should be maintained at a 50%-50% mixture (by volume) of water and ethylene glycol. The fluid should be checked in August and again in January to insure the system is protected from freezing throughout the winter season.

5.1 Ground Array Water/Ethylene Glycol Mixture

A sample of fluid in the ground array plumbing system may be obtained by opening the hose bib valve on the ground array collector loop in the basement. (This valve is tagged and is readily identifiable.) No more than a half pint of fluid is needed to determine the percent of ethylene glycol in the mixture by a hydrometer test. (Plastic sample bottles are located in the basement.) If the percent of ethylene glycol in the mixture is below 50 percent, some of the fluid must be drained from the system and then replaced by pumping an equal amount of pure ethylene glycol back into the system. Figure 6 shows the proper amount of fluid to be drained and replaced for various percentages of ethylene glycol originally present. If the required amount of fluid to be drained cannot be obtained from the hose bib valve in the basement, it will be necessary to drain the fluid directly from the collectors. Refer to Figure 2 and Figure 3 for complete instructions on draining fluid from the ground array. Note that it is also possible to refill the ground array system either from the hose bib valve in the basement or from hose bib valve #13 (see Figure 2) on the ground array. A female-female connector hose is available in the basement to connect a pump to either of these recharge (i.e., refill) locations. After the array has been refilled with ethylene glycol it is extremely important to verify that the desired 50%-50% water-ethylene glycol mixture has been obtained. (NOTE: A mixture of 60 percent ethylene

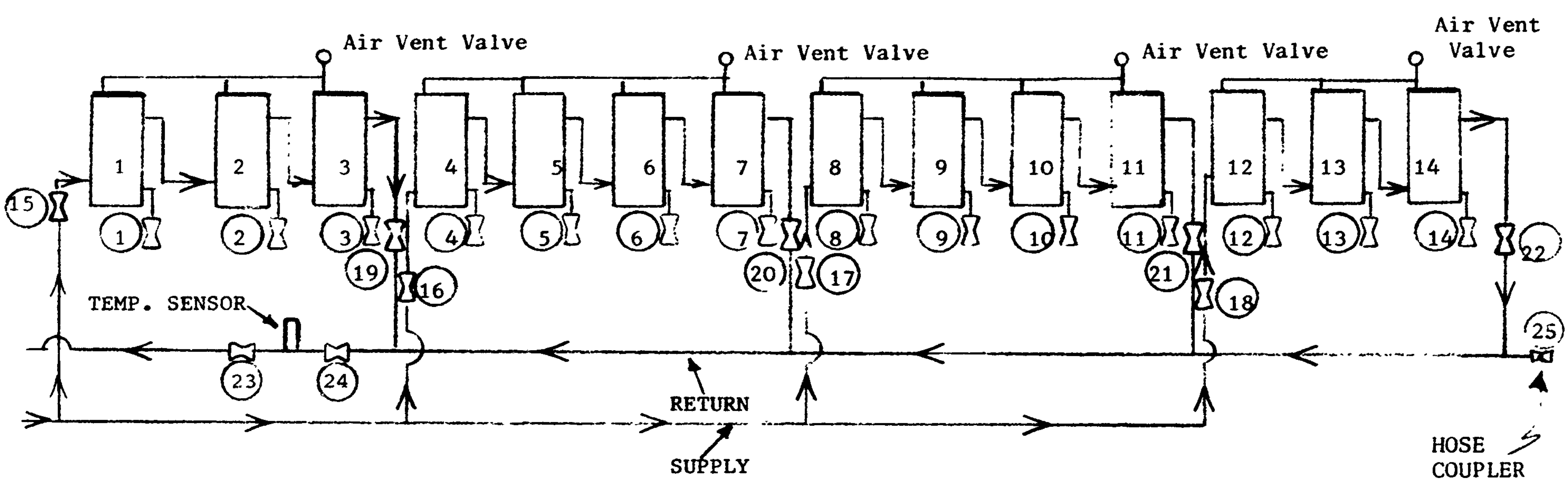


FIGURE 4

ROOF ARRAY SCHEMATIC WITH VALVE NUMBERING SYSTEM

Panel Numbers	To Drain for Maintenance or Repair		For Normal Operation of System	
	Close Valves	Open Valves	Closed Valves	Opened Valves
1	15, 19	1	1	15, 19
2	15, 19	2	2	15, 19
3	15, 19	3	3	15, 19
4	16, 20	4	4	16, 20
5	16, 20	5	5	16, 20
6	16, 20	6	6	16, 20
7	16, 20	7	7	16, 20
8	17, 21	8	8	17, 21
9	17, 21	9	9	17, 21
10	17, 21	10	10	17, 21
11	17, 21	11	11	17, 21
12	18, 22	12	12	18, 22
13	18, 22	13	13	18, 22
14	18, 22	14	14	18, 22
Entire Array (All Collectors Simultaneously)			1-14 & 25	15 - 24

NOTE: To insure complete draining of collectors be sure to break the vacuum by loosening or removing the air vent valves.

FIGURE 5. PROCEDURES FOR DRAINING AND REFILLING ROOF ARRAY FOR ROUTINE MAINTENANCE OR REPAIR

glycol gives maximum freeze protection; pure ethylene glycol will freeze nearly as quickly as pure water.) The collector loop should be allowed to run for a few hours to insure that the ethylene glycol which was added to the system has the opportunity to mix thoroughly with the rest of the fluid in the system. If a test sample is withdrawn before adequate mixing has occurred it will give erroneous results. THIS COULD LEAD TO FREEZE DAMAGE OF ALL COLLECTORS. If the fluid mixture checks satisfactorily, tag the basement hose bib valve with the charge date and exact concentration of ethylene glycol.

5.2 Roof Array Water/Ethylene Glycol Mixture

The roof array mixture must be checked and maintained similarly to the ground array mixture. Samples are obtained by opening the hose bib valve located on the roof array collector loop in the basement. (This valve is also tagged.) If ethylene glycol must be added to the system, fluid may be drained and glycol pumped in via the same valve. (It is not necessary to drain the array directly from the collectors, i.e., from the roof.) Figure 6 also shows the proper amount of fluid replacement for the roof array. The pump used for recharging the system must be able to develop at least 15 psi pressure to overcome the static head developed by the fluid in the roof array collectors. Note: It is possible, though not necessary, to refill the roof array system from hose bib valve #25 (Reference Figure 4) located on the eastern end of the array.

5.3 Bi-Annual System Draining

Ethylene glycol eventually deteriorates and becomes corrosive. For this reason, the roof and ground array systems should be drained and flushed every two years. This operation should be done during

Desired fluid mixture is 50% ethylene glycol and 50% water.

% of Ethylene Glycol in System (Hydrometer Test Results)	Gallons of Fluid to be Drained and Replaced by the Same Amount of Ethylene Glycol
50%	None
45%	2 ½
40%	4
35%	6
30%	7
25%	8 ½
20%	9 ½
15%	10 ½
10%	11
5%	12
Zero	12 ½

FIGURE 6. FLUID REPLACEMENT AMOUNTS

August to coincide with the annual freeze protection schedule recommended in paragraph 5.0 above. After flushing, the water should be completely drained from both arrays. A 50%-50% mixture (by volume) of water and ethylene glycol should then be pumped into both systems until they are completely recharged. Remember to tag the hose bib valves of both array loops in the basement with the recharge dates. Recharging must be accomplished in early morning to prevent vaporization of fluid in hot collectors. If fluid is added to hot collectors "vapor locking" will occur. A water make-up system to add city water to each array is installed and clearly tagged in the basement. This system can be used to aid in the recharging operation if desired. NOTE: It is vitally important that this automatic make-up system be turned OFF during winter operation. If a system leak developed and the make-up system was ON, the glycol would become diluted and freeze protection would be lost.

6.0 Underground Storage Tank

An underground reinforced concrete storage tank is used to store thermal energy in the form of hot water. The tank is located on the northwest corner of the house as shown in Figure 1. A manhole at ground level permits entry into the top of the tank. Primary reasons for needing access to the tank would be for maintenance or repair of the heat exchangers submerged in the tank, replacement of the temperature sensor suspended in the tank, or structural repair to the tank itself.

The tank has a 2500 gallon capacity. Most efficient solar heating occurs when the tank holds only 1400 gallons. This occurs when the levelometer located in the basement by the pumps reads 2' 3". This reading corresponds to the fluid just covering the top of the heat exchangers in the tank. Water level in the tank should be checked

(August, January). Care should be taken not to cause accumulation of debris in the storage tank water (e.g., pieces of insulation, etc.). This debris could obstruct the pipe which conveys the hot storage tank water to the water-to-air heat exchanger in the return air plenum; this obstruction would, of course, result in no solar energy being provided to the home.

7.0 Routine Maintenance Schedule

This paragraph summarizes the items which should be checked during the August and January visits to the solar home.

a. Inspect the plumbing system in the basement for leaks at joints, pump seals, gauges, valves, etc. An outside "walk-around" check of the collectors could reveal leaks also.

b. Check for broken glass covers on all collector panels.

c. Check all pump couplers in the basement for wear. Replace as necessary.

d. Lubricate all pumps as required.

e. Check both expansion tanks in the basement for fluid penetration through the diaphragm (see Appendix 3 for the expansion tank manufacturer specifications).

f. Check storage tank levelometer to insure proper water level in underground storage tank.

g. Perform operational check on pressure relief valves on both collector arrays.

h. Clean out pipe strainers in basement. The collector array loop strainers should be cleaned concurrently with the bi-annual system draining and recharge (reference paragraph 5.3). The heat coil loop strainer (located ahead of Pump #4) should be cleaned every August.

i. Obtain collector fluid samples from both arrays and check for freeze protection (reference paragraphs 5-5.2). Add ethylene glycol as necessary.

j. Accomplish complete collector loop draining, flushing and recharge every other August (i.e., every two years). Recharge only when collectors aren't hot, e.g., early morning, late evening or very cloudy periods.

k. Check collector array loop pressures. Pressure should not go below 10 psi gauge; water can be added to either loop through the make-up system to raise pressure. Remember, a persistently decreasing pressure reading probably indicates a leak. Continually adding pure water to a collector loop will result in loss of freeze protection. NOTE: Do not leave water make-up system on.

l. Check operation of solar controller. The Activity Light should be blinking. If it is sunny outside, both collector loop lights and the collector pumps should be running. Refer to the descriptions of the controller display panel which appear in the Homeowners Manual (Appendix 4) for further information regarding controller operation.

8.0 Extra Collectors

Extra Revere collectors are available for replacement use. They are located in the ground array A-frame shelter.

9.0 The Solar Controller Program

This section very briefly describes how the Solar Controller operates the heating system.

If the flat plate absorbing surface of the ground array collector panels is 20°F higher than the water in the underground storage tank,

the ground and roof array collector pumps will come on. These pumps will also come on if the plate temperature is 170°F or higher, regardless of the storage tank temperature. These pumps will remain on as long as the working fluid in the collector loops is 4°F higher than the storage tank water. If the collector fluid and storage tank temperature difference goes below 4°F, the collector pumps will shut off.

If the home requires heat and the temperature of the storage tank water is 86°F or higher, the controller will turn on the heat coil pump (Pump #4). Forty seconds after the pump starts running, the furnace fan is turned on. When the home reaches the desired interior temperature, Pump #4 will shut down. Forty seconds later the furnace fan turns off.

If the home requires heat and the temperature of the storage tank is, or goes, below 86°F, the controller will turn on the gas furnace. The furnace fan will come on normally after a short period, i.e., the Solar Controller does not control the fan when the gas furnace is heating the home.

10.0 Solar Controller Maintenance Checklist

It is recognized that most electricians are not familiar with solid state controllers. If the controller malfunctions it is believed, however, that carefully following the checklist below will result in successful repair.

I. Activity Light Not Blinking

A. Insure controller is plugged into wall socket.

1. Check two plugs:

a. From microprocessor in Controller Box to outlet box mounted on the side of Controller Box.

b. From outlet box on side of Controller to wall socket box.

B. Open Controller Box and check the duplicate light on the microprocessor marked "Activity".

1. If the duplicate is operating, replace the 4049(2) chip on computer that serves the external LED (Light Emitting Diode) socket. (Scotchflex connector goes from this socket to the front panel lights.) A spare 4049(2) chip is available in the Controller Box. If light still does not work, replace it with a spare LED available in Controller Box.

> NOTE: Always unplug computer before replacing any chips or LED's. Replace all chips carefully in exactly the same way they were removed from their socket. Pin No. 1 is usually marked with a dot. If the dot is not present, Pin No. 1 is located on the upper left of the notched end.

2. If the duplicate LED on the microprocessor (inside the Controller Box) is not operating, then you must assume that the microprocessor has malfunctioned. Take the following actions:

a. Check the voltages on the microprocessor's power supply unit. The correct voltage readings are indicated on the power supply unit. If they are erroneous, this unit must be replaced.

b. If the problem is not in power supplies, then start replacing chips one at a time (replace one, then check operation) starting with number 8154. One set of labeled spare chips is in the Controller Box. See Note above!

II. Controller Display/System Incompatibility

A. If the controller appears to be functioning correctly but the system is not, e.g., a display light is on but the respective mechanical device is not operating, take the following actions in order indicated:

1. Check the applicable device, e.g., power supply to the pump or fan, pump coupler, etc.

2. Replace the crydom switch for the applicable unit. The crydom switches are clearly labeled in the metal box near the Solar Controller. (See Figure 7.)

B. If a mechanical device is on and its respective Controller light is not on, take the following actions in order indicated:

1. Open Controller Box and check the respective duplicate light on the microprocessor.

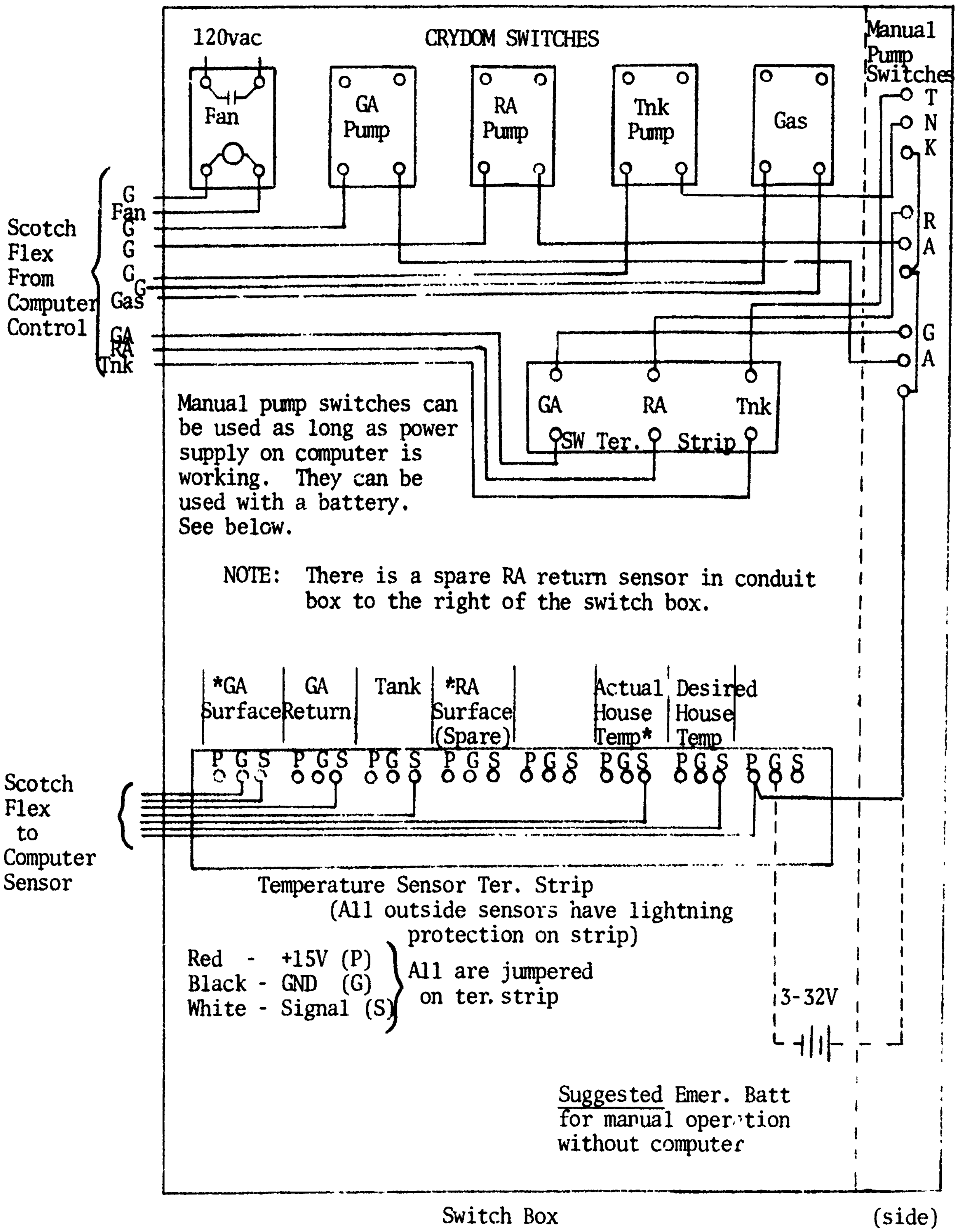


FIGURE 7. CRYDOM/SENSOR BOX WIRING DIAGRAM

a. If this light is on, replace the chip numbered 4049(2). See Note below! If the main display light will still not operate, replace it with a light from the spares available in the Controller Box.

b. If the duplicate light on the microprocessor is not on, then replace the 74LS374, 8154, and Z80 chips in that order. (Replace one, then check operation.)

NOTE: Always unplug computer before replacing any chips or LED's. Replace all chips carefully in exactly the same way they were removed from their socket. Pin No. 1 is usually marked with a dot. If the dot is not present, Pin No. 1 is located on the upper left of the notched end.

III. Activity Light Blinking but Controller Malfunctioning

Many different types of malfunctions are theoretically possible; the following represents those that are most likely to occur.

A. If it is midday on a sunny day and the collector arrays are not functioning (i.e., GROUND and ROOF ARRAY lights not on and pump numbers 1 and 2 not on) the following action should be taken. Open the Controller Box and replace the following chips on the microprocessor in this order: 74LS374, 8154, 2708. Replace each chip, then check Controller operation before replacing the next chip. See above Boxed-In Note before replacing these components!

B. If the Controller display lights and their associated mechanical devices are not operating properly, e.g., pumps or fan go on and off erratically, a pump or fan will either not come on or will not go off, collector array pumps 1 and 2 operating at night or extremely cloudy days, etc., take the following actions:

1. Check the temperature sensor input readings to the microprocessor. The procedure follows: Open the metal box near the Solar Controller and identify the clearly labeled sensor inputs. (See Figure 7.) Take voltage readings between G and S (ground and signal) on each sensor input line. A zero volt reading indicates that the sensor is inputting a temperature reading of $0^{o}F$ to the microprocessor. A ten volt reading indicates a temperature reading of $255^{o}F$. Volt and temperature readings between those extremes are in a direct linear relationship, i.e., one volt increments correspond to $25.5^{o}F$ temperature differences.

a. House actual temperature reading: If this sensor input reads significantly different from the true house temperature (55-$75^{o}F$ temperature would correspond to a 2.1-3.0 volt reading) then this sensor needs replacing. The sensor is located in the exterior wire mold box next to the conventional wall-mounted thermostat in the living room. Sensor ordering information is given in Appendix 2 of this manual.

b. Storage tank temperature reading: In all probability the reading for this sensor will fall between 3 and 6 volts. If the reading is significantly different than this, the sensor should be replaced. The sensor is located in the copper pipe which is suspended in the underground storage tank. Sensor ordering information is given in Appendix 2. A good way to check this sensor's operation is to remove it from the storage tank water and see if its voltage output takes on the reading corresponding to the outside ambient temperature.

c. Ground array absorber surface temperature reading: This reading can fluctuate widely depending upon weather conditions and if the collector pumps are running. If this sensor input reads zero volts and the outside temperature is not zero or below, the sensor probably needs replacing. This sensor can read ten volts if it is midday on a hot, sunny day and the collector pumps aren't running. If it is determined that this sensor has failed, there are back-up sensors already installed and available on several of the ground array collectors. It is only necessary to enter the ground array frame shelter, locate another sensor's lead-in wires, and wire them up to the existing transmission wire. Be careful to connect it identically to the way the failed sensor is wired up. In addition, a spare surface sensor on the roof array is already wired up and the output is available and labeled in the metal crydom/sensor box. It is only necessary to disconnect the Scotchflex wire from the failed ground array surface sensor and connect it to the spare roof array surface sensor output. (This spare roof array surface sensor also provides the capability to correlate its voltage/temperature reading to that of the ground array surface reading--if they both read nearly the same then both are probably in good operating order.) See Appendix 2 for information on how to order new sensors for the ground array surface. It is felt that sufficient backups are available on the ground array, however, to preclude having to order a replacement.

d. Ground array return fluid temperature reading: This reading can also show wide variance depending on weather conditions and whether or not the collector pumps are running. If the collector system is not running and the actual outside temperature is zero or below, a zero volt reading would be correct. A zero volt reading in any other circumstance, however, would indicate sensor failure. It is extremely unlikely that a reading higher than seven volts would ever be encountered for this sensor. If it is determined that this sensor has failed, it can be replaced in accordance with instructions contained in paragraph 3.2 of this manual. Pending replacement of this sensor on the ground array and to restore system operation immediately, a back-up has been provided on the roof array. The wire connected to this sensor is available in the metal conduit box located to the right of the crydom/sensor switch box. It is only necessary to pull this wire into the crydom/sensor switch box and wire it into the Scotchflex terminal which was connected to the ground array return sensor. (This spare roof array return sensor also provides the capability to correlate its voltage/temperature reading to that of the ground array return reading--if they both read nearly the same then both are probably in good operating order.) See Appendix 2 for information on how to order a new sensor for the ground array return fluid port.

e. Desired house temperature reading: The source of this reading is the thermostat on the Solar Controller. This makes it very easy to check this sensor output. If the thermostat is set on 60°F the voltage reading should be approximately 2.3 volts, if set on 80°F the voltage reading should be approximately 3.1 volts, etc. It is considered extremely unlikely that this thermostat system would malfunction.

2. If, after determining that all temperature sensors are operational, the system is still malfunctioning, open the Solar Controller Box and replace the following chips on the microprocessor in the order indicated: H1818A, 741, ADC, 81LS95, 8154. Replace each chip, then check Controller operation before replacing the next chip.

NOTE: Always unplug computer before replacing any chips or LED's. Replace all chips carefully in exactly the same way they were removed from their socket. Pin No. 1 is usually marked with a dot. If the dot is not present, Pin No. 1 is located on the upper left of the notched end.

3. If, after replacing all the chips, the Controller is still malfunctioning refer to paragraph V below.

IV. Manual Switching of Pumps If, for maintenance or trouble shooting purposes, it becomes desirable to turn on the collector array pumps (pump nos. 1 and 2) or the storage tank pump (Pump #4) independently of Solar Controller, the toggle switches on the side of the crydom/sensor box (see Figure 7) can be used. If the Solar Controller is outputting no power (e.g., unplugged or microprocessor power supply inoperative) a 3-32 volt DC battery should be installed as shown in Figure 7. This battery will provide enough power to the crydom switches to turn the mechanical units on and off.

V. Contract Maintenance of Solar Controller If in-house forces are unable to repair a malfunctioning Solar Controller, it will be necessary to obtain contract maintenance assistance. A copy of this maintenance checklist and Appendix 5 (Instrumentation and Control System) must be provided to the vendor. It is further suggested that the Solar Controller microprocessor not be removed from the house, i.e., the contractor technician should check out the system in place before it is removed.

REVERE COLLECTOR SPECIFICATIONS

Atch 1

REVERE

THE REVERE SOLAR ENERGY COLLECTOR

for new and existing buildings

This catalog was prepared to provide architects and engineers with the necessary data to design efficient systems to collect solar energy and to use it for heating or air conditioning both residential and commercial buildings. The technical information presented here has been documented by experimental work at Revere's Research Center in Rome, N.Y., through the performance of many Revere Solar Collector installations throughout the country, and through many years of experience with a wide variety of copper building products.

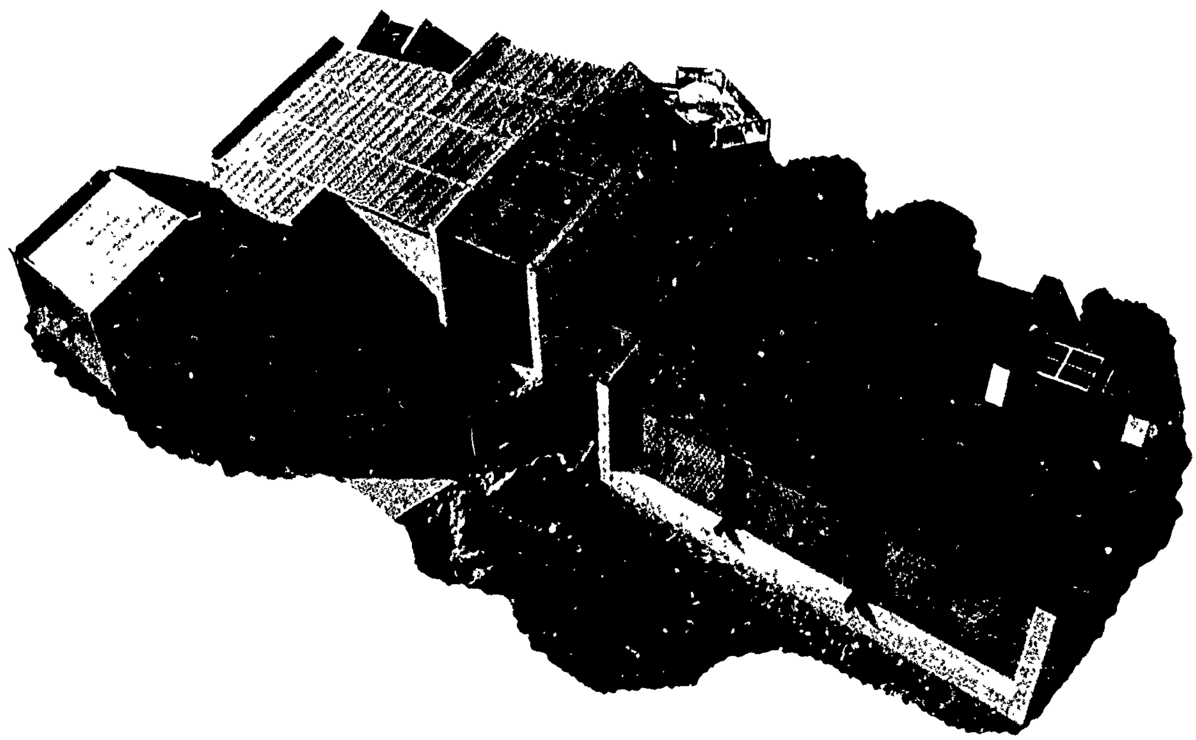
The Revere Solar Energy Collector was designed as an extension of the Revere Copper Laminated Panel System. However, the solar collector may be used independently for applications such as heating water for swimming pools.

The Revere Solar Energy Collector

Since 1801, Revere Copper and Brass Incorporated, in the tradition of its skillful and ingenious founder, Paul Revere, has consistently developed its products and expanded its operations to meet industrial demand for nonferrous metals and products. In addition to its complete line of copper and copper-base alloys in standard mill form, Revere is now fully integrated in aluminum from mining to mill fabrication, to subassemblies. A wide range of metal extrusions, building products, metal foils for decorative and industrial uses, condenser tubing, electrical switches and the famous Revere Ware cooking utensils are some of the numerous products made by this growing corporation.

The long-established and highly qualified Revere Technical Advisory Service has worked closely with architects, engineers and contractors in the development of new and improved products for the building and construction industry. Throughout the country, Revere copper water tubes are the arteries of countless heating and cooling systems, both residential and commercial. The company's long experience with this product has been of vital assistance in accumulating the technical data for the new Revere Solar Energy Collector.

REVERE



D 25

for new and existing buildings.

Rapid changes in the cost and availability of natural gas, oil and electricity have created an intensive demand for alternate energy sources. Among these alternate energy sources, the most plentiful and least expensive is solar energy. In addition to its inherent advantages such as unlimited supply, wide availability and non-pollution of the atmosphere, solar energy is a form which may be extracted efficiently with presently available technology. Harnessing of the sun's power has not previously been employed in this country on a large scale because of the availability of inexpensive fossil fuel sources. Now high costs and shortages of these fuels have changed the picture dramatically.

Revere Copper and Brass Incorporated developed and has been marketing two basic types of collectors for gathering and using solar energy —collectors that are economically feasible for both new and existing buildings.

The first type of collector is the Revere Combination Roof and Solar Energy Collector, which consists of a laminated panel roofing system, plus the necessary additional components to convert it to a solar collector. These additional components include tubes, clips, tapes, sealing strips, and support members for the glass. The addition of glass, insulation, and a weatherproof flashing system completes the installation and results in an efficient and maintenance-free solar energy collector which fulfills a dual function as roof and solar collector for the structure on which it is installed.

The second type is a modular unit, fully assembled and prepiped, ready for connection to an existing piping system. This unit, which is described on page 5, may be installed on a framing system or, if installed in small quantities, on a simple support bracket. Its aluminum casing and all-copper heat transfer components assure the user of a long lasting and reliable solar energy collector.

Revere Solar Energy Collectors are efficient, easy to install, long lasting, maintenance-free, and reasonably priced. They offer for both residential and industrial applications a practical and readily available means to combat the energy shortage and overcome the high cost of fuel. Revere Solar Energy Collectors can heat a fluid more than 100° above the surrounding air temperature and are practical for a variety of uses; from heating a swimming pool to providing hot water, heat and air conditioning.

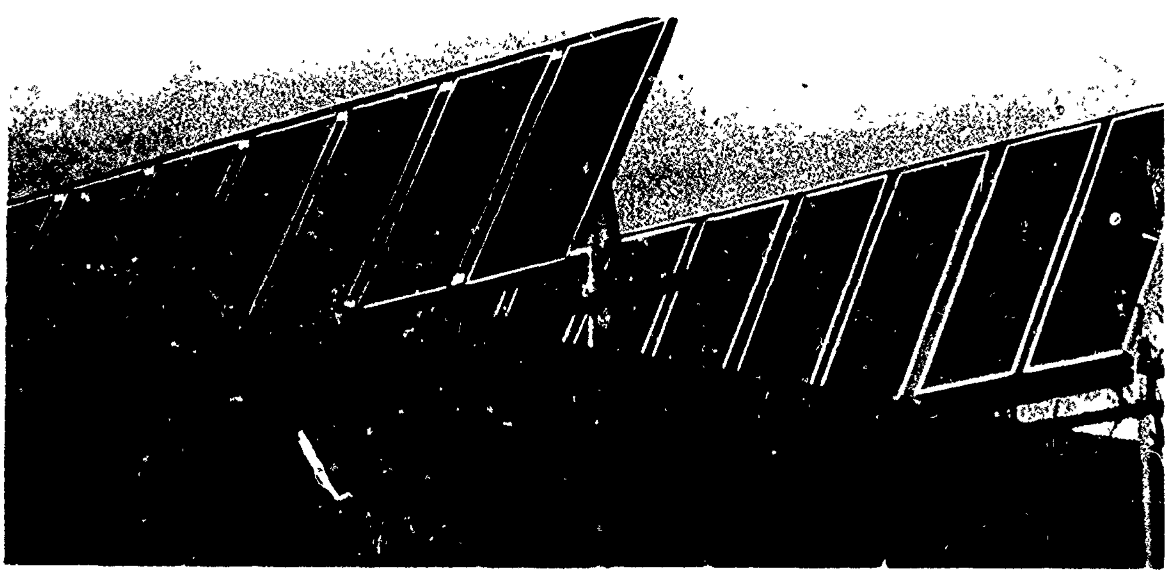
Both models of the Revere Solar Energy Collector have been developed as an extension of the established Revere System of Laminated Panel Construction. In the Revere Panel System, copper sheet is laminated to plywood to make a copper composite building panel. Joints between the copper laminated panels are sealed with special roll-formed copper joint members and high-grade sealing tape. *An illustrated brochure describing the Revere System of Laminated Panel Construction is available from the Revere Building Products Department or through your local Revere Laminated Panel Distributor.*

Solar Energy Collectors and Their Uses.

Applications for solar energy collectors include heating domestic water, buildings and swimming pools, and for furnishing heat to operate absorption type air conditioning units. Solar energy collectors also have exciting potential uses in commercial laundries, drying of agricultural products and other industrial applications. Each of these calls for the solar energy collector system to perform somewhat differently. An installation in which domestic water is heated does not usually require water temperatures much higher than 140°F. However, an application for heating a building might require water temperatures up to 170°F.

Absorption air conditioning units will require water temperatures near the boiling point, whereas swimming pool heaters will usually function at temperatures 5-20° above the surrounding air temperature.

The information contained in this book is offered as an aid in the design and application of the solar system best suited to fit your needs.



For new buildings

Revere Combination Roof and Solar Energy Collector

The Revere combination unit was developed from the Revere laminated panel system for use on new construction to function as both a weathertight copper roof and as an efficient solar energy collector.

To convert an installation of the Revere laminated panel system to a solar collector, rectangular copper tubes are secured to standard 2 feet by 8 feet panels with copper clips. A special high conductivity adhesive is applied between tube and panel to insure a good heat transfer characteristic. Tube spacings may vary from 4 inches to 8 inches on center, depending upon efficiency requirements.

A specially constructed copper batten supports one or two layers of glass or other transparent material.

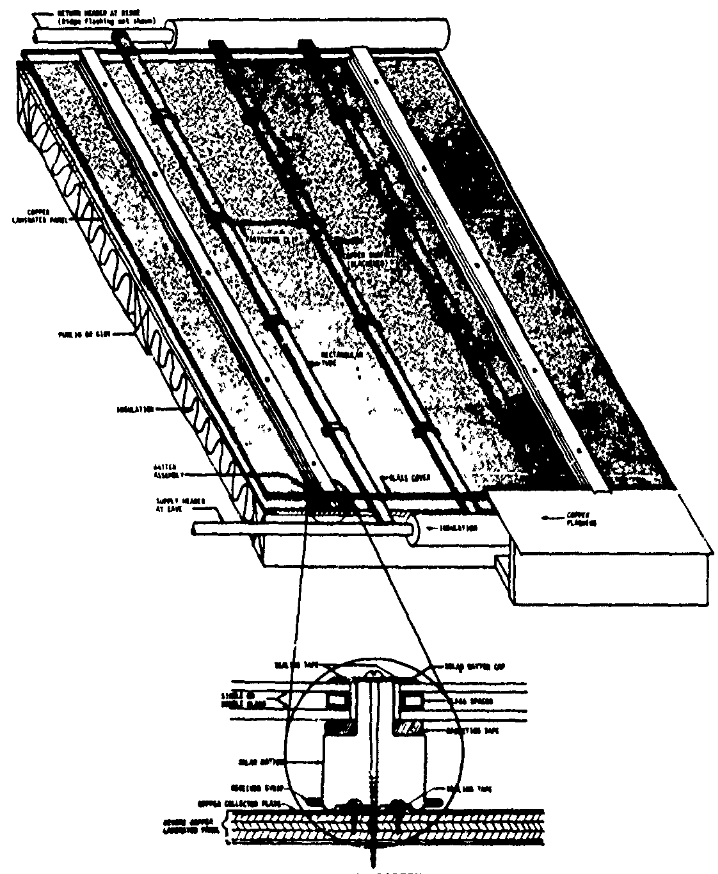
Revere has also developed simple adapter fittings to facilitate the connection of the rectangular tubes to conventional round copper water tubes.

On these units the battens, tubes, cover pieces, receiver strips, headers, clips, conductive adhesive, sealing tapes, necessary adapter fittings, and paint are supplied by Revere.

To eliminate breakage and minimize shipping costs, glass for the solar collector may be procured locally. Glass with low iron content is best for transmitting the maximum amount of the sun's radiant energy.

The standard coating used on the Revere Solar Energy Collector is a high-quality, heat-resistant, flat black paint. With proper application this provides a surface which will absorb 95% of the solar energy which touches it.

Revere Combination Laminated Panel Roof and Solar Collector



Advantages of the Revere Combination Roof and Solar Collector

1. Low in-place cost. Since the solar collector also functions as a roof, the normal cost which would be assigned to the roof of the structure may be deducted from the effective cost of the solar collector.

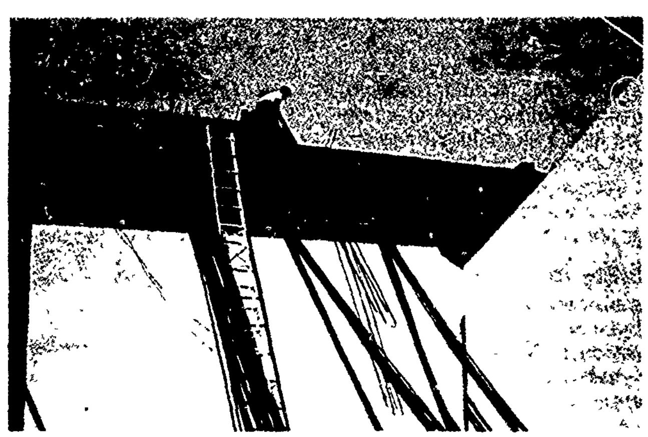
2. Easy Installation. The combination roof and collector is quickly and easily installed with only the simplest carpenter tools The all-copper piping is joined by standard and well-known fabricating methods.

3. Long life. The use of copper for the fluid pathway and heat transfer surface is your best assurance of long life for a solar collector system. Copper has consistently proved its worth as a dependable and long-lasting construction material in millions of water tube and roofing installations.

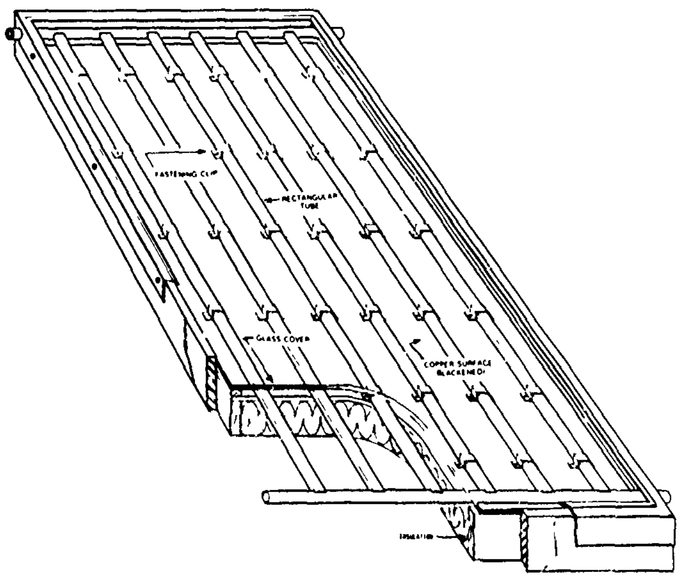
4. Maintenance-free. The collector surfaces expose only copper, glass, and the highest quality sealant tapes to the weather. These high quality materials assure the user a minimal amount of maintenance on the system.

How the Revere Solar Energy Collector Works

Operation of the Revere Solar Energy Collector is simple. A blackened copper surface absorbs radiant heat and transfers it to a fluid circulated through tubes which are fastened securely to the absorber surface. The collector plate is usually covered with glass, or other transparent material, which admits radiant energy from the sun, but traps any energy which is re-radiated from the warm surface.



REVERE For existing buildings



Revere Modular Solar Collectors

Revere Modular Collectors are prepackaged and prepiped units for use on new or existing construction. A mounting bracket kit is available for residential and small commercial installations, while angled support frames are used on large installations and flat roof construction. These units are simple, competitively priced, and they incorporate a number of outstanding features in their construction:

Outstanding Features of the Revere Modular Collector

Simple Piping Connections

The header ends project through the sides of the modular unit housing and are easily joined by standard solder type fittings to both supply and return piping.

Transparent Cover

The standard cover of the Revere Collector is two layers of tempered glass which permit the sun's rays to enter and heat the fluid in the tubes, but prevent the heat from escaping. The glass may be either low iron or on special order, water white crystal to further increase the collector capacity. Single layer covers are also available for use determined by geographical location and unit efficiency requirements.

Insulated Housing

Insulation for the modular collector unit consists of 3½" of fiberglass beneath the heat absorbing surface and 1" of rigid urethane on the sides of the casing. Corrosion-resistant aluminum is used to cover the structural framework for the unit.

Flexibility in Construction

On special order the number and spacing of the tubes can be varied to best suit individual requirements. In like manner, the tube circuiting and type of transparent covering can be modified

Quality Components

The collector plate is constructed of Revere copper sheet for highest heat transfer efficiency and best corrosion resistance.

The ½" x 1" rectangular tubes, also made of Revere copper, are fastened to the collector plate with copper clips to assure good contact between the tubes and the plate A conductive sealant is used between the tubes and collector plate to provide the highest degree of heat transfer. The tubes, which are spaced 5½" on centers, are brazed into conventional ¾" (nom.) round Type L copper water tube headers.

Efficient Absorbing Coating

The standard coating used on the modular collector is the same high quality, heat resistant, highly absorbent paint that is used on the combination roof and collector.

For enhanced performance, Revere can supply an optional selective surface on the tubes and absorbing surface of its solar energy collector. A selective surface is a special finish which absorbs solar energy with a high degree of efficiency but does not reradiate it in any significant quantities Because of this, losses through the glass are minimized and performance of the unit is improved.

Applications of Solar Energy Collectors

The most common applications for Revere Solar Energy Coll' ctors are domestic water heating, space heating, air conditioning, and swimming pool heating.

Domestic Water Heating

Although domestic water requirements will vary widely, 20 gallons per person per day is the usual daily hot water requirement for residential usage.

A combination of lower solar radiation levels, plus lower water and air temperatures, makes the winter heating requirement from 2 to 5 times greater than the summer requirements.

In the southern United States, two collectors per 4 or 5 person family will normally supply most of the domestic hot water. For applications in the north or for larger families, it is customary to add one to three additional collectors

In areas not subject to freezing, installations can usually be piped directly into the domestic water heating circuit. However installations in colder climates will require a circuit which uses an antifreeze solution or includes provision for emptying the circuit manually or automatically in the event of freezing conditions.

Supply and return lines should be well insulated so that most of the heat obtained from the system is retained and transferred to the storage tank.

Domestic water heating systems may be divided into two classifications.

1. Gravity—In gravity systems no pump is used to circulate the domestic water. It is circulated by the convective forces caused when the fluid in the solar collectors becomes warm due to sunlight shining on the collectors. The hot water, which is less dense, rises into a storage tank. In applications of this type, it is important to place the storage tank at least one foot above the top of the solar collectors, to insulate the supply and return lines well and to place a check valve in the supply line to prevent reverse circulation during cold periods. In addition, it is important to oversize the lines between the collector and the storage tank and to pitch them properly to prevent airbinding or reduced circulation.

2. Forced Circulation—Circulated or pumped domestic water heating systems are similar to conventional hot water heating systems in their piping layout and pump sizing, except for any differences in pump selection made necessary by the use of ethylene or propylene glycol. Pumps which circulate the domestic water should be bronze. For residential applications, a ¾" (nominal) supply and return line will be sufficient for 2 collectors, while a 1" tube can supply up to 5 collectors piped in parallel. For larger systems and commercial installations, the collectors may be connected in series to reduce the necessary water quantities and keep tube sizes (and piping costs) to a minimum.

Storage tanks for domestic water heating applications are usually sized to hold between 1½ and 2 gallons per active square foot of collector surface.

Space Heating

Collectors for space heating should be mounted at angles of inclination to favor the months of November through March. For the best or optimum slopes, refer to chart on page 8. As with domestic water heating systems, in some areas it will be necessary to provide for drainage of the system in cold weather, or to use antifreeze in the collector piping.

In a self-draining or "dump" type system, it is imperative that all piping be pitched properly so that no pockets of water are left in the system.

Cross connections between the potable water system and the antifreeze loop of a solar collector system should be eliminated to prevent the contents of the two from intermixing.

An automatic water make-up valve should not be used in systems employing antifreeze since over a period of time this could result in dilution of the antifreeze and possibly lead to a system freeze up.

Pumps which circulate antifreeze solution should be sized so that they can handle the additional load caused by increased viscosities of antifreeze solutions.

For space heating, the collector is usually sized between 30 and 50% of the floor area of the building, although smaller areas may be practical in very well insulated structures. The area of the collector will vary according to the geographic location of the installation, the insulation in the house, amount of window and door area, and the overall efficiency of the collector.

Storage tanks for space heating are commonly sized to hold between 1 and 2 gallons per square foot of collector surface. The interior surface of the storage tank should be coated or otherwise protected to prevent corrosion over extended periods of use.

For collector installations of several hundred square feet or larger, it is usually advantageous to circuit several collectors in a series. If the installation is a combination roof and collector type, tube lengths up to 25 feet and circuit lengths upwards of 25 to 50 feet can be used. This has the effect of minimizing flow quantities and piping sizes while not penalizing the system performance

In designing solar energy heating systems, use the lowest practical fluid temperature which can heat the structure. Systems which make use of low temperature fluids, such as radiant heating systems, are especially good applications.

Swimming Pool Heating

Solar collectors can be used to effectively heat swimming pools. Revere manufactures a solar swimming pool heater, described in a separate piece of literature, which uses the same basic tube and collector plate assembly as the Revere Solar Collectors previously described. The basic swimming pool collector, which does not require a glass cover, should be used to heat pool water approximately 5-10 degrees higher than the surrounding air. For applications where a greater differential between swimming pool water and surrounding air temperatures is required or where pool heating is desired on a year round basis, collectors with a single glass cover may be used.

A solar collector area approximately equal to 50% of the pool is used in many cases, although smaller amounts have been used in geographic locations of high solar insolation.

Heating and Air Conditioning

In most installations which use solar collectors for both heating and cooling, the air conditioning requirements will be greater than the heating requirements. For this reason, the inclination of the roof or solar collector bank will usually be tailored to fit the air conditioning requirements rather than the heating requirements.

This can usually be accomplished without incurring any significant losses in the winter heating capability of the collector system. The chart on page 8 gives an indication of the loss in heating capacity for collector inclinations other than the optimum for winter heating. The most common method of air conditioning with solar energy is by means of absorption-powered air conditioners. Depending upon the efficiency of the unit and the solar intensity from 250 to 330 square feet of collector surface may be required per nominal ton of air conditioning. The use of solar collectors to drive absorption air conditioners requires fluid temperatures in the neighborhood of 190-210°F. For this reason, it is again important to insulate carefully and to the greatest extent economically feasible.

Heat Pump Systems

Solar collectors may be used as a heat source for heat pump systems in which the heat pump will transfer heat to a storage tank This hot water in the tank can then be used in periods of cooler weather for space heating The advantage of this type operation is that air conditioning and heating are provided by a single unit, with solar collectors increasing the efficiency of the heat pump system As heat pumps become more efficient, and energy costs continue to rise, this type of application, illustrated on page 10, will become increasingly more common.

D-29

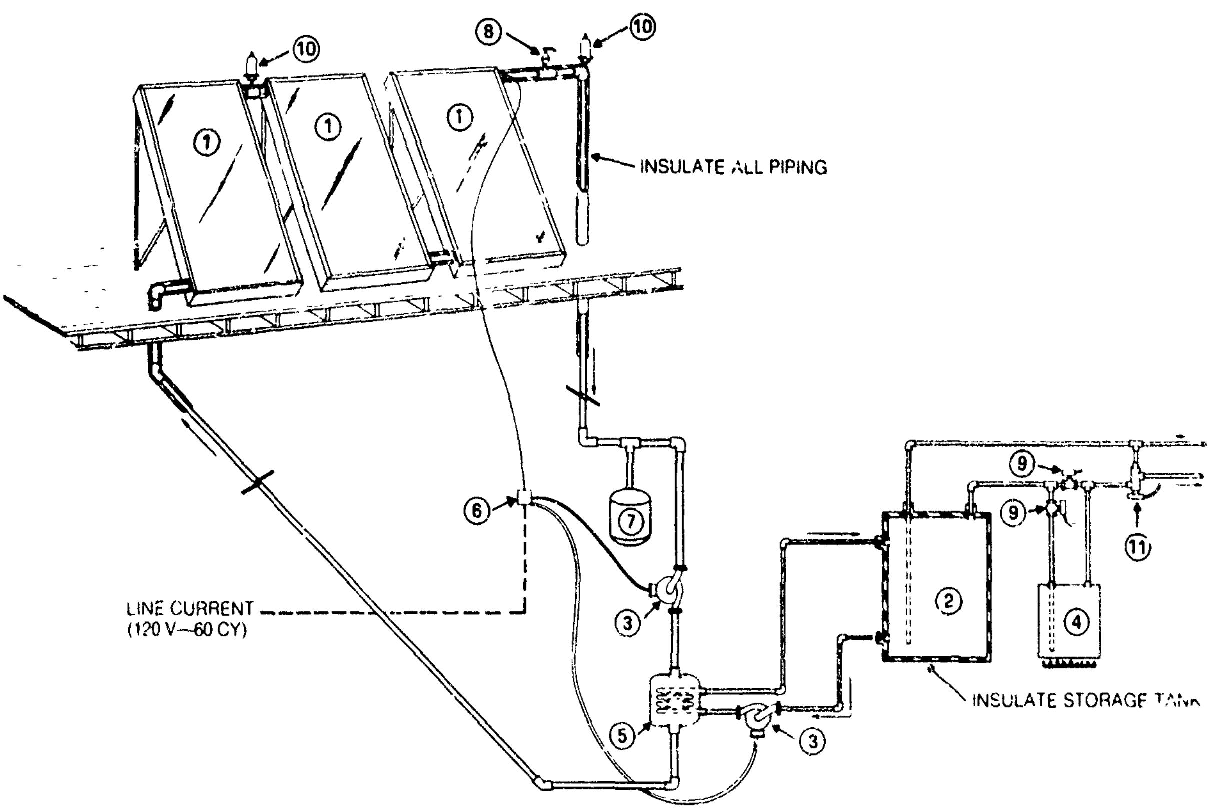
REVERE Design suggestions

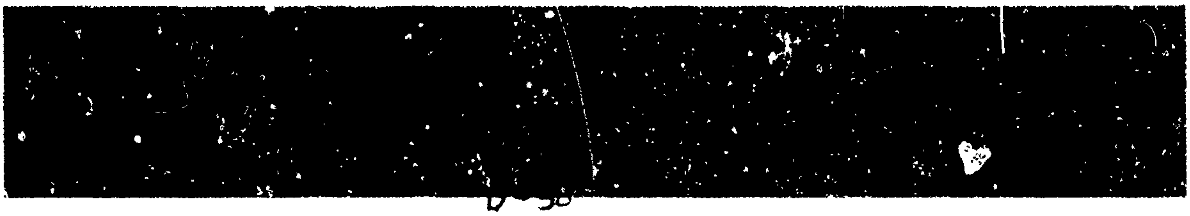
Design Suggestions for a Solar Energy Collector

The following suggestions are offered to aid in the design of a smooth functioning, economical solar energy collector:

- Where possible, design a collector for multiple use and make it an integral part of the building—collector and roof, fascia or curtain wall combined.
- Make piping network and control system as simple as practical.
- Insulate piping and collector well to minimize heat losses.
- Keep circuits at reasonable lengths to prevent excessive head pressure drops or high temperature rises within each circuit.
- Avoid "short circuiting" or unequal water flow. Include balancing valves wherever possible to permit proper system balancing.
- Provide air vents at high points of system.
- Avoid water velocities greater than 4 feet per second in the collector tubes.
- Follow manufacturers' recommendations in the selection of pumps and heat exchangers for use with antifreeze solution.
- Size domestic water heating storage tanks to hold 20 gallons of water per user as a minimum, with 30 gallons of water per user a preferable figure.
- For domestic water heating an optimum collector size is approximately ⅔ square foot of area per gallon of water storage.
- For space heating of residences and small commercial applications the collector is commonly sized between 30 and 50% of the internal floor area.
- For space heating of large commercial applications, collector areas less than 30% of the internal floor area can still provide significant heating cost reductions.

Typical Solar Space Heating System.





Design • Yield • Spacing

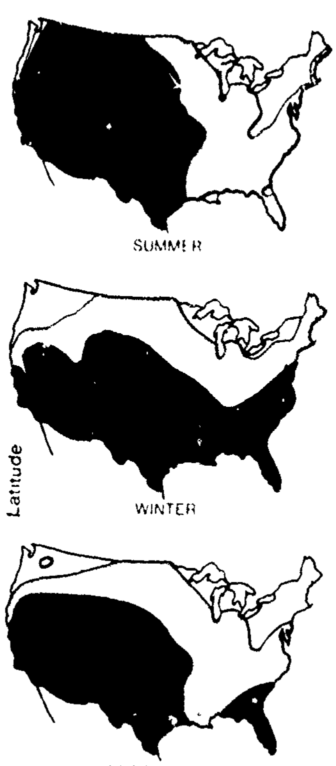
Design of Solar Energy Collection System

Local weather conditions can greatly affect the amount of solar energy which can be collected. The ratio of clear, sunny days to cloudy days is of greater importance than temperature variations. A cool region with a large number of clear days could have a greater potential for collecting solar energy than a warm area with a large percentage of cloudy days.

The solar potential of an area can be evaluated by referring to solar insolation maps such as those issued by the U.S. Weather Bureau. Any such evaluation should consider seasonal variation in both solar input and required unit output. For example, a collector used for heating a building would require maximum output during winter, whereas a collector used to heat water for domestic use would require a relatively constant output all year.

The adjacent charts give solar insolation values for applications which are primarily Summer, Winter and year-round respectively.

RELATIVE SUITABILITY FOR SOLAR ENERGY COLLECTION



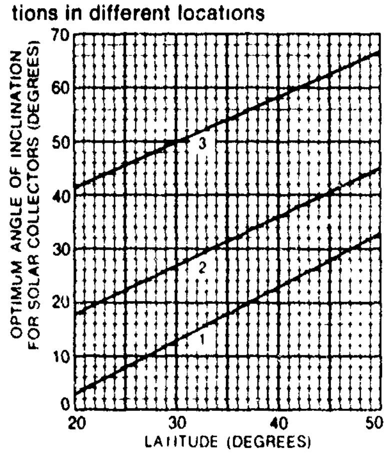
EXCELLENT — GOOD

VERY GOOD — FAIR

Maximizing Solar Yield

To obtain the greatest solar yield from a solar collector it is important that the collector be oriented correctly The best direction for a solar collector to face is due south, at a slope perpendicular to the sun's rays. Small variations from a due south direction will not affect the capacity greatly, but if the unit orientation is to vary more than 45° from due south, an analysis should be made to determine the loss in unit capacity.

The position of the collector must sometimes be a compromise between the optimum collection angle and the roof slope of the building. Since the optimum collector slope varies with the latitude, season and application, a designer is referred to the adjacent chart for the optimum slopes for solar collectors used for various installations in different locations



OPTIMUM COLLECTOR SLOPES vs. LATITUDES
Curve 1—Angle for maximum summer insolation
Curve 2—Angle for maximum year-round insolation
Curve 3—Angle for maximum winter insolation

Minimum Collector Spacing

When collector banks are set in back of one another, low winter sun can cause shading and loss in capacity unless the units are carefully spaced. The table below gives a minimum spacing between rows of collectors which are installed vertically

SPACING BETWEEN ROWS TO PREVENT SHADOWING (FEET)

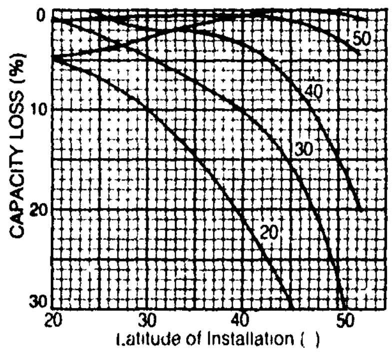
VERTICAL COLLECTOR 6½

Collector Angle of Installation	Latitude of Installation (°) 30	35	40	45
30°	9.9	11 1	12.6	13.7
45°	10.6	12 2	14.4	16.0
60°	10.7	12 6	15 4	17 2

Reduced Heating Capacity due to Collector Angle

The curves below indicate a reduction in capacity during the heating season due to collector angles which vary from the optimum angle by being too steep or too shallow.

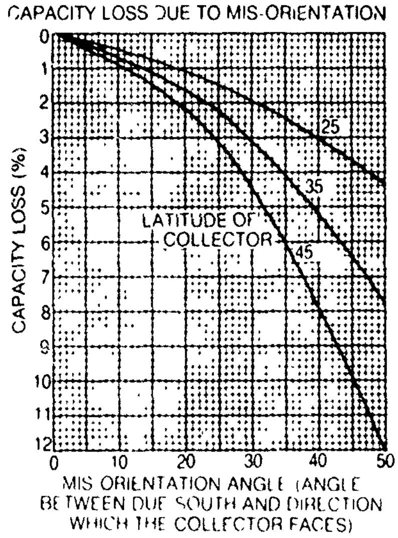
CAPACITY LOSS DUE TO COLLECTOR ANGLE



Reduced Heating Capacity due to Poor Collector Orientation

Due to building orientation and sun obstructions, such as trees, it is not always possible to have solar collectors face the best direction. Optimum facing is slightly west of south due to the higher afternoon temperatures and slightly higher solar insolation values in the afternoon. The chart below indicates the approximate reduction in capacity due to collectors which face away from due south Note that the reduction is not appreciable for collectors facing as much as 45 degrees away from due south.

CAPACITY LOSS DUE TO MIS-ORIENTATION



Solar Energy Collector Ratings

Determining Collector Ratings

The adjacent graphs give approximate instantaneous ratings for the Revere Solar Energy Collector. The use of these ratings, in conjunction with records of solar insolation values such as those available from the U.S. Weather Bureau for the geographical areas under consideration, will enable the user to obtain estimated yearly panel inputs. The curve on the bottom right approximates the capacity of the modular collector units.

Example

A total system capacity of 250,000 BTU/hr. is required from a 2000 sq. ft. solar energy collector system with an average panel water temperature of 120°F, a solar input of 250 BTU/hr./sq. ft. and an ambient temperature of 80°F. The panel configuration that meets these capacity requirements can be determined as follows:

$$\text{Required output} = \frac{250{,}000}{2000} = 125 \text{ BTU/hr./sq. ft.}$$

$$\text{Required panel efficiency} = \frac{\text{output}}{\text{input}} = \frac{125}{250} = 50\%$$

Average panel water temperature minus ambient temperature = 120°–80° = 40°

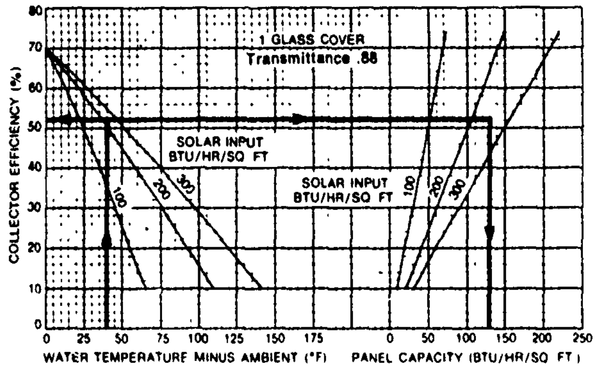
At the above conditions, a panel with tubes 8" on centers and a single glass cover has an efficiency of 52% and an approximate output of 130 BTU/hr./sq. ft. If higher capacities were required, a unit having either single or double glass and tubes 5½" on centers could be used.

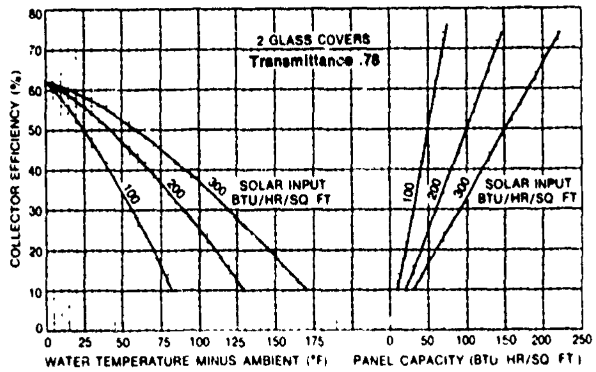
THE TABLE BELOW SUMMARIZES AVERAGE COLLECTOR EFFICIENCIES AND OUTPUTS FOR VARIOUS APPLICATIONS.

Application	Solar Input	Season	Avg Eff (%)	Avg. Output—BTU/HR /SQ FT
Swimming Pools	Good Very Good	Summer	60 70	120 175
Heating Domestic Water	Good Very Good	Summer	50 60	100 150
	Good Very Good	Non-Summer	45 50	90 125
Heating	Good Very Good	Spring/Fall	40 45	80 115
	Good Very Good	Winter	30 35	60 90

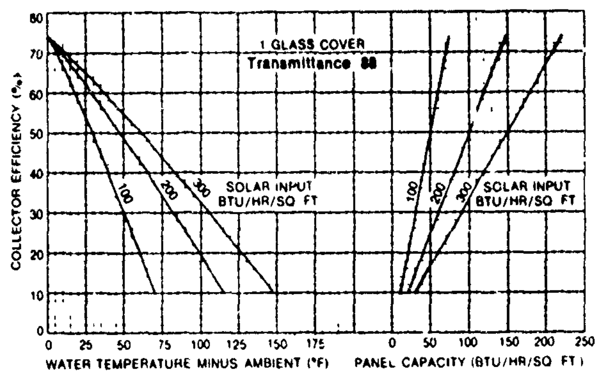
1 Solar Input— Good —200 BTU/Hr /Sq Ft
Very Good—250 BTU/Hr /Sq Ft

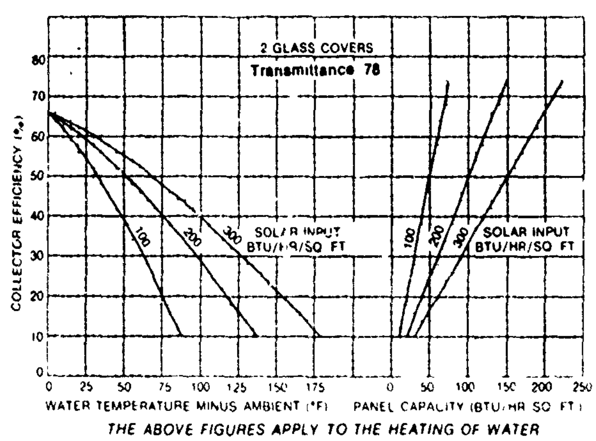
SOLAR ENERGY COLLECTOR SYSTEM RATINGS
3 TUBES PER TWO FEET WIDE PANEL





SOLAR ENERGY COLLECTOR SYSTEM RATINGS
4 TUBES PER TWO FEET WIDE PANEL



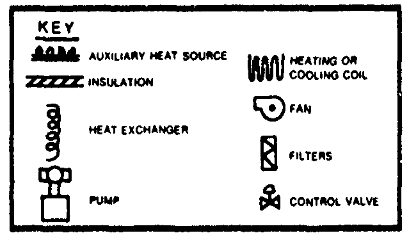


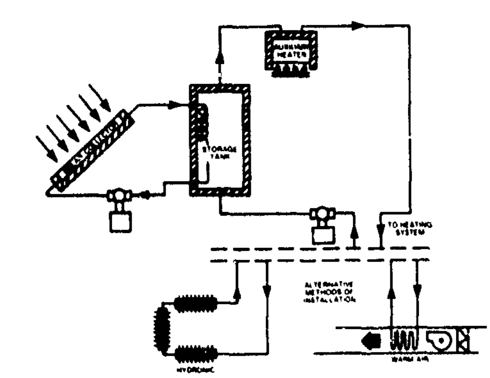
THE ABOVE FIGURES APPLY TO THE HEATING OF WATER

Piping System Design

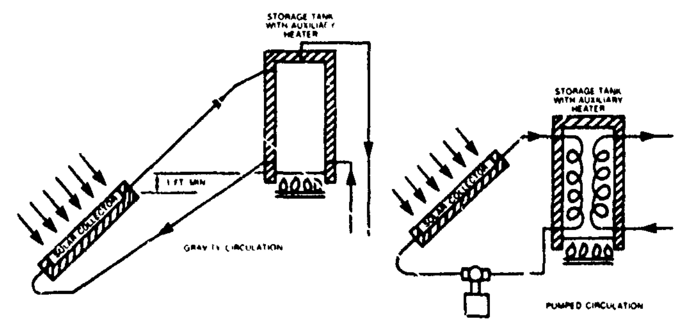
Piping design for solar energy collector systems does not vary greatly from conventional heating systems. The main difference is the fluid used in the collector circuit. In areas where the temperature may fall below freezing an antifreeze solution should be used in the collector pipes which gather the heat and convey it to an insulated storage tank. The antifreeze is then passed through a heat exchanger where the heat is extracted and transferred to water which is pumped to the point of use.

The diagrams below show simplified piping configurations for a number of different solar energy collector applications.

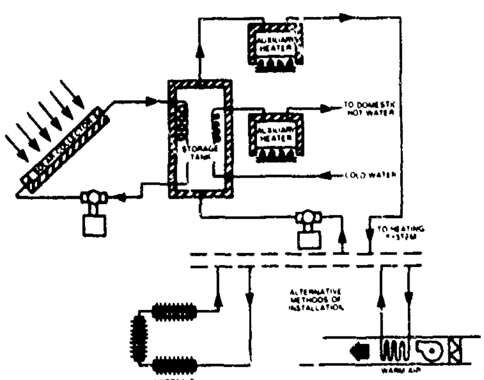




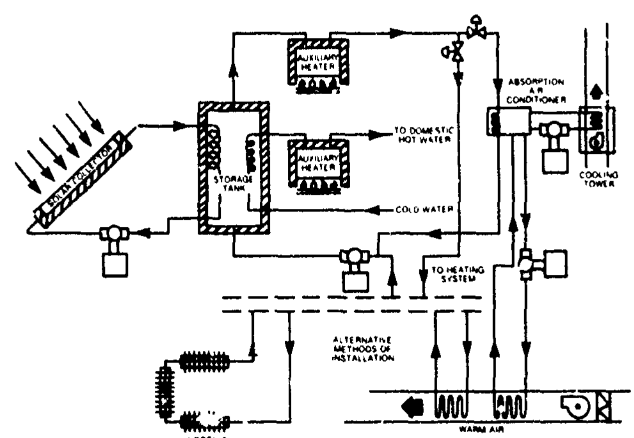
HEATING



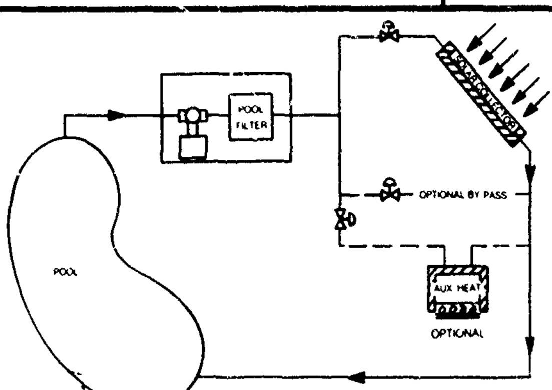
DOMESTIC WATER HEATING



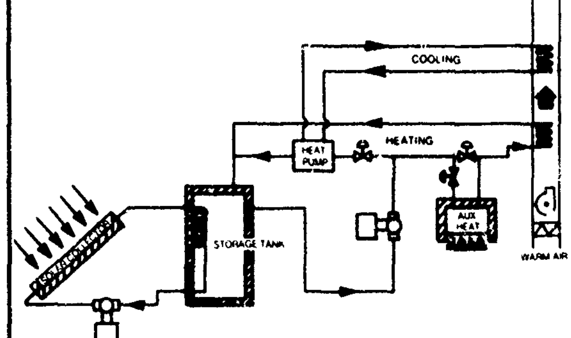
HEATING & DOMESTIC WATER



HEATING, AIR CONDITIONING & DOMESTIC WATER



SWIMMING POOL HEATING



HEATING & AIR CONDITIONING WITH HEAT PUMPS

Revere Copper and Brass Incorporated

Collector Piping Design and Use of Antifreeze

Ethylene glycol, the most commonly used antifreeze, is slightly more dense and has a lower specific heat than water. As a result, an ethylene glycol/water solution holds less heat than a corresponding amount of water. The following equations will aid in the computation of heat content and friction pressure drop for different ethylene glycol/water mixtures.

BTU/HR = GPM × (Ent. fluid temp.—Lvg. fluid temp.) × 500 × C
Friction pressure drop = pres. drop for water × frict. correction factor.

ETHYLENE GLYCOL CORRECTION FACTORS

% Glycol	Temp. (°F)	C	Friction Correction Factor (For Equal Flow Rates)
0	100 200	995 .975	1.00 1.00
25	100 200	.956 .944	1.05 .96
50	100 200	.830 820	1.10 .92

Note: Do not use an antifreeze solution with greater than 60% ethylene glycol since this may result in damage to the system.

Tube sizing and pressure drop calculations for the remainder of the system are calculated in the same manner as in conventional heating systems.

The rectangular collector tubes have an internal area and pressure drop rate approximately the same as ¾" (Nom.) Type K copper water tube.

Materials for Solar Energy Collectors

Revere's Research Center has generations of experience with many materials. After thorough analyses of a wide variety of metals and non-metallic materials, we came to the conclusion that *copper has the best combination of properties for solar energy collectors for these reasons:*

■ **Copper transfers heat best.** Copper's heat transfer values are two to eight times better than any other material considered for collector plates.

■ **Copper resists corrosion.** No other metal has a better record of long-term corrosion resistance than copper.

■ **Copper is easy to install.** The use of solder fittings, familiar to the trades, insures fast, simple, inexpensive installation. With the Revere system there are no expensive or complicated joining procedures.

■ **Copper stays strong.** High temperatures, such as 210°F water, do not cause any significant loss of strength.

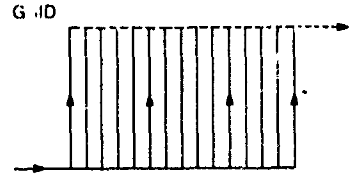
■ **Copper requires no inhibitors.** Other materials need inhibitors, which require periodic replenishment, to prevent corrosion. Copper does not need such inhibitors.

In the Revere system the collector plate surface, tubes, clips, fittings and battens are all 100% copper and are compatible with copper or other distribution piping materials.

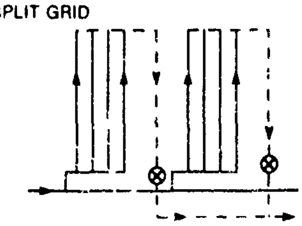
Types of Circuiting for Solar Energy Collectors

In general, piping layout for a solar collector follows the same concepts that govern any piping network. Several types of circuiting layouts which may be used for different applications are illustrated below.

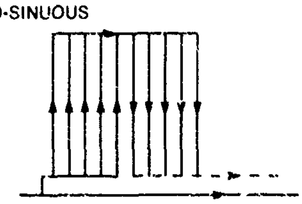
GRID



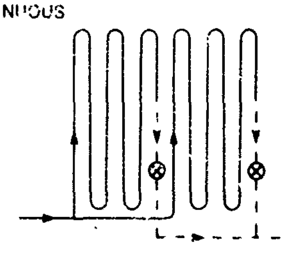
SPLIT GRID



GRID-SINUOUS



SINUOUS



Revere Copper and Brass Incorporated

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Phone: 687-4111 *Area Code: 212* *Teletype: 212-640-5298* *Cable: REVERECOP—New York*

telephone no.

Building Products Dept.: P.O. box 151, Rome, NY, 13440 .... *315-338-2401*

General Offices: P.O. box 191, Rome, NY, 13440 .... (Teletype: *510-243-9233*) *315-338-2022*

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1801 REVERE ®

TEMPERATURE SENSOR INFORMATION

Atch 2

TEMPERATURE SENSOR INFORMATION

There are two types of temperature sensors in use on the solar home. Both are available from Relco Products, Inc., 5594 East Jefferson, Denver, Colorado, 80237. Their telephone number is (303)756-1143.

The first type of sensor is used to detect the temperature of the absorbing plate of the ground array collectors. This type is also used to sense the actual temperature of the home's interior. This latter sensor is located in the exterior wire mold box located next to the conventional wall-mounted thermostat in the home's living room. This type of sensor is Model #1710.

The second type of sensor is used to detect the collector fluid temperatures and the storage tank water temperatures. This type of sensor is Model #1068.

The following requirements must be adhered to when ordering replacement sensors:

Model - 1068 or 1710

Sensitivity - 100 millivolts/^{o}C

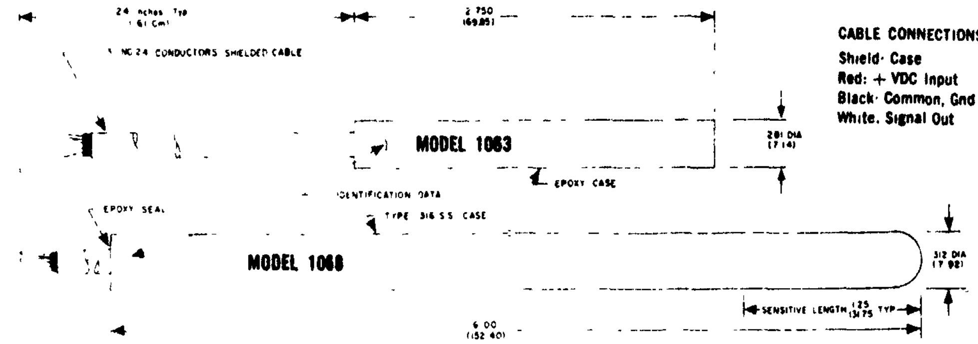
Full Scale Temp - Positive 125^{o}C

Output Voltage - +10V

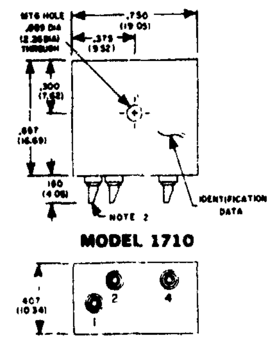
Supply Voltage - +15V

NOTE: The syster will run incorrectly if sensors are installed that output different voltages for a given temperature than those currently in use.

TEMPERATURE TRANSDUCERS



CABLE CONNECTIONS
Shield: Case
Red: + VDC Input
Black: Common, Gnd
White: Signal Out



PIN CONNECTIONS
1. Signal Out
2. + VDC Input
4. Common, Gnd

SPECIFICATIONS

ELECTRICAL

Range	Any range between -75 and +140°C (−100 to +285°F) The transducer may be operated continuously at cold temperatures down to −100°C and intermittently up to +150°C
Sensitivity	Any sensitivity up to 200 millivolts/°Celsius (111 mv/°F). Tolerance on the slope is ± 2% but can be trimmed to exact value with external circuitry. See application notes
Full Scale Output Voltage	Full scale output voltages up to +9 volts may be specified. Tolerance on the F.S. output ± 2% but can be trimmed to exact value with external circuits
Output Impedance	The transducer output or source impedance ranges from 4000 to 5000 ohms.
Load Impedance	The transducer is designed to operate into a standard external load of 100 kohms ± 1%. External loads ranging from 10 kohms and greater may be specified.
Time Constant (Note a)	Model 1063 10 seconds, Model 1068 15 seconds, Model 1710 15 seconds
Linearity (Note b)	± 1.5% of span −35 to +110°C ± .5% of span −60 to +130°C
Stability	± 1°C over 90 days
Accuracy	The transducer can be calibrated at the factory to an accuracy of ± 1°C within the span of −40 to +110°C The minimum calibration point always starts at a transducer output of > +1 volt
Supply Voltage	+15 vdc ± .03% is standard Transducer reference is derived from the supply and if maximum accuracy is not required, a larger tolerance on the supply voltage is permissible
Power Consumption	10 to 25 milliwatts typical
Self Heating Error	.004°C per milliwatt power dissipation typical with the transducer mounted in place.

NOTE a Time Constant, The time required for a 63% response to a step change from 24 ± 4°C to an oil bath (#200 Dow Corning 1.5 CTSK at 76 ± 4°C and flowing at 3 fps transverse to the sensing surface is less than the figure given The in service response will depend upo how it is mounted and the environment in which it is used

NOTE b The maximum error incurred when the best straight line fit is used to approximate the transfer characteristic is as specified For transducer models using a single positive supply voltage, the straight line fit is between 20% and 100% of full scale output

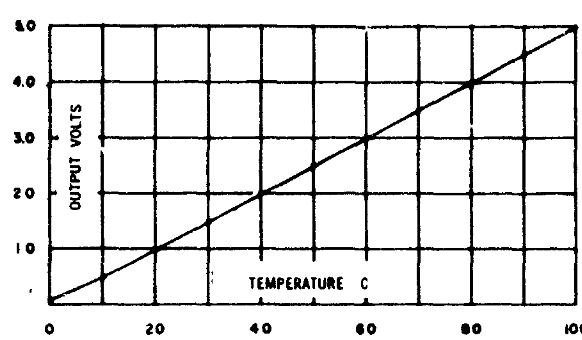
NOTE 2: Solder cup for a maximum wire size of one No. 20 AWG

HOW TO SPECIFY:

To order, specify the model number, required sensitivity in millivolts per degree **Celsius**, full scale temperature in degree **Celsius** together with sign, full scale output voltage, and supply voltage. In addition, specify any special requirements such as load impedance

1710 S050 P100 – 5 (15V)

- + supply voltage in parentheses Example, +15 VDC
- Full scale output voltage. Example, +5 VDC
- Dash
- Full scale temperature in degrees Celsius
- P for positive N for negative, Z for zero.
- Sensitivity in millivolts per degree Celsius.
- Model designation



~~LCO PRODUCTS, INC. (303) 756-1143
5594 EAST JEFFERSON • DENVER, COLORADO 80237

U S PATENT 3,708,755

Prices Model 1063 $19.50 Model 1068 $24.50 Model 1710 $24.50 Add $15.00 each for factory calibration Quantity discounts available

SOME TYPICAL SOLID STATE TEMPERATURE TRANSDUCER APPLICATIONS

INTRODUCTION: This note describes four applications employing Solid State Temperature Transducers similar to the ones described in Electronics[1]. The three models covered by the specification are complete self contained units having the sensing transistor, bridge and feedback amplifier packaged together as a single complete system. Connections are by three terminals, +15 vdc, common and output signal. The signal appearing between the signal and common connections is a voltage which linearily increases with increasing temperature. The rate of increase and the voltage at full scale temperature are fixed by internal system resistors, therefore, these parameters must be specified when ordering. Due to the fact that the entire transducer system is exposed to the sensed temperature, the temperature extremes and some performance parameters are slightly different from the system described in the referenced article.

ENVIRONMENTAL MEASUREMENTS: A number of current applications involve gathering temperature data accurate to $\pm$.1°C with a resolution of .01°C from the ocean and atmosphere. Sea water measurements for the range of -5 to +35°C use a transducer having a sensitivity of 100 mv/°C and a F.S. voltage of +5 vdc at +35°C so that the output ranges from +1 to +5 volts. The linearity of the transducer makes system calibration simple as only three points are required, i.e. 0 and +35°C with a third point at 20°C for a calibration check.

PRECISION LABORATORY OR CLINICAL DIGITAL THERMOMETER: A low cost accurate and stable digital thermometer can be constructed by using transducers having a sensitivity of ten millivolts per degree. The circuit of Figure A is designed to both minimize the power supply sensitivity and provide bipolar temperature readings. For the C scale, the designated transducers have an output of 4.5 V at 0°C. A digital panel meter measures the transducer output with respect to 4.5V displaying magnitude and polarity with the least significant digit representing .1°. Calibration is accomplished by first placing the transducer into an ice bath (0°C) and adjusting the zero potentiometer for a display of 00.0. Next the transducer is placed into an oil bath of approximately +100°C and the gain potentiometer is adjusted to provide the correct display as determined from a reference thermometer. This system can provide temperature measurements accurate to $\pm$.2°C over the span of -40 to +120°C. The construction of a Fahrenheit scale digital thermometer is the same except that the reference level is 5.63 V. Note that transducer part numbers are specified in terms of the Celsius scale and 10 mv/°F is equal to 18 mv/°C.

Experimental clinical thermometers for the span of +25 to +50°C and having an accuracy of $\pm$.05°C have been tested using transducers with a sensitivity of 100 mv/°C (i.e. Models 1063S100P50-6 & 1068S100P50-6). The circuit of Fig. A was used except the reference was made +1 V and the inherent stability of the regulator circuit shown was relied on to minimize transducer power supply sensitivity. A 4 1/2 digit DPM was used in this application.

TEMPERATURE CONTROLLER: The proper development and printing of color photographic materials is critically dependent upon the temperature of the chemical baths. Figure B shows the schematic diagram of a temperature controller which when used with the circuit of Fig. A provides an accurate control of chemical bath temperature. The only change in Fig. A is that the "High" input to the DPM goes to a SPDT switch and then to point "C". The temperature set point is adjusted by switching the DPM as shown and adjusting the temperature set point potentiometer for the desired value as indicated by the DPM. When the bath temperature falls below the set point temperature the comparator output driver operates an optical coupler which in turn actuates a Triac and causes the heater to be connected across the AC line. A light emitting diode provides visual indication of controller operation.

LOW TEMPERATURE ALARM A frost warning alarm for a fruit orchard was constructed by replacing the heater in the above controller with an audio visual alarm system. The actual installation dispensed with the DPM and used a D'Arsonval meter to indicate temperature. Also the set-point potentiometer was replaced by a set of fixed resistors and the alarm temperature was selected with a rotary switch. It should be noted that by interchanging the connections to pins 1 and 2 of the 311 comparator one can change the circuit into a high temperature alarm.

CONCLUSION: The transducers covered by the specification use discrete components to obtain reliable operation over the maximum range of -100 to +150°C. The output impedance is relatively high therefore unless another value is specified, the transducers are constructed to operate into a fixed external load of 100K. Loss of output caused by smaller loads can be made up by an external amplifier as is shown in Fig. A.

1. Robert A. Ruehle, "Solid-State Temperature Sensor Outperforms Previous Transducers", Electronics, March 20, 1975, Vol. 48, No. 6, Page 127 - 130, McGraw-Hill, 1221 Avenue of the Americas, New York, New York.

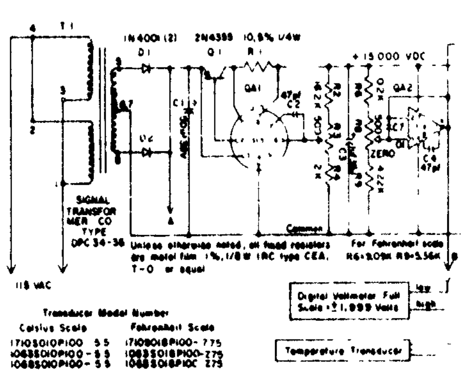


Figure A Digital Thermometer

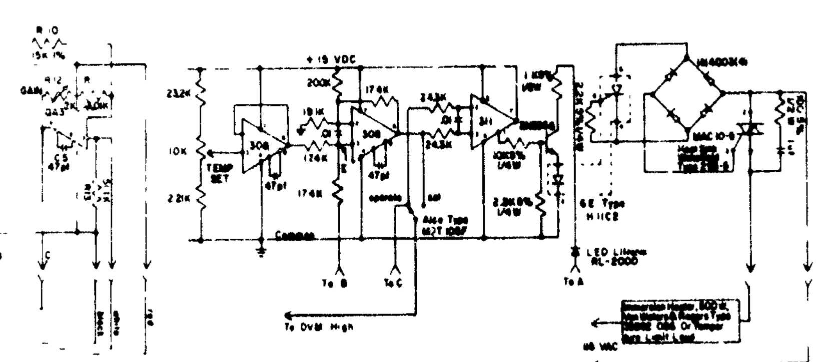


Figure B Temperature Controller Or Low Temperature Alarm Also Used For High Temp Alarm, See Text

RELCO PRODUCTS, INC. 5594 EAST JEFFERSON • DENVER COLORADO 80237 • PHONE (303) 756-1143

TEMPERATURE TRANSDUCERS

DESCRIPTION

These temperature transducers are all solid state devices which use a silicon transistor as the temperature sensor operated in a proprietary circuit made up of a self-adjusting bridge and a feedback amplifier [1] The solid state temperature transducer was invented at Rel Products in 1966 and the original applications were in the military and aerospace fields [2] Continuous refinement has both improved the performance and reduced the cost so that today these precision devices are used in numerous commercial and industrial applications such as Measurement and control of residential solar heating systems, Monitoring process temperatures in a chemical factory, Measurement of cold storage temperatures in a supermarket; Monitoring the temperature of oil well logging instrument packages Mil grade components are used exclusively for reliable operation over the span of -100 to +150°C

Relco temperature transducers are complete self-contained units which supply a linear high level signal directly to recording and control instruments without additional external resistance networks or amplifiers. Three categories of transducers are covered in this data sheet

Models 1063A, 1068A, 1710A and 1067A are electrically identical differing only in packaging. Model 1063A is a general purpose low cost epoxy unit. Model 1068A is housed in a stainless steel case for immersion applications; Model 1710A is intended for mounting to surfaces by means of a single 2-56 screw through the unit. Model 1067A is for those applications requiring a stainless steel case and a hermetic conector. These four models derive their internal reference from the supply voltage and require an accurate well regulated power supply Figure 1 shows a typical application together with a graph of the output signal for the part illustrated.

Model 1810 has a +10 volt reference built into the unit so that it can be operated from an unregulated power supply This reference voltage is available at the transducer for use by low power signal conditioning modules such as voltage to frequency converters

Model 420 provides a current output corresponding to the industrial standard of 4 to 20 milliamperes This unit is for use in two wire systems such as shown in Figure 2 See also reference 3 for a precision control interface for use with model 420

1 Robert A. Ruehle, "Solid-State Temperature Sensor Outperforms Previous Transducers," Electronics, March 20, 1975, Volume 48, No. 6, Page 127-130, McGraw-Hill, 1221 Avenue of the Americas, New York, New York

2 Patented, U.S. 3,708,785, Canada 966,902, G B. 1,372,917, U S. and foreign patents pending

3 "Linear Data Book," National Semiconductor Corp , Santa Clara, California, June 1976, P 2-4

SPECIFICATIONS

	Models 1063A, 1067A, 1068A, 1710A	Model 1810	Model 420
RANGE	Any range between -100 and +150°C (-150 & +300°F) The transducer may be operated intermittently up to +180°C	Any range between -55 and +125°C (-67 and +257°F)	
ACCURACY	±½% F S. or ±.5°C. The transducer can be factory calibrated to an accuracy of ±.1°C within the span of -40 to +110°C The minimum calibration point always starts at a transducer output of > +.75 volts		±1% F S or ±1°C. The transducer can be factory calibrated to an accuracy of ± 3°C within the span of -40 to +110°C.
LINEARITY (Note 2)	± 15% of span -35 to +110°C, ± 3% of span -60 to +130°C	± 15% of span -35 to +110°C; ± 3% of span -55 to +125°C	
OUTPUT SIGNAL	A linear voltage which increases with increasing temperature ranging from zero volts up to the full scale value specified (Note 3)		A linear current which increases with increasing temperature ranging from 4 ma at 0% of span to 20 ma at 100% of span
SENSITIVITY	Any sensitivity up to 250 millivolts per degree Celsius may be specified (139 mv/°F)		Any sensitivity between 80 & 320 microamperes/°C (44 & 178 ua/°F) may be specified
MAXIMUM FULL SCALE OUTPUT (Note 7)	V supply / V out max: +15 / +12 +12 / +9 +10 / +7.5 +5 / +2.5	+7.5 volts	20 milliamperes
SUPPLY VOLTAGE	Standard. +15, +12, +10 and +5 volts, ± 1% regulated Optional Any regulated voltage from +5 to +25 volts, ±.1%	+15 V unregulated nominal, +12.5 V minimum, +30 V maximum (Note 4)	+24 V unregulated nominal, +12.5 V minimum, +35 V maximum
OUTPUT IMPEDANCE	25 ohms typ , 10 ohms minimum, 35 ohms maximum		The transducer is a current source with a high source impedance
LOAD IMPEDANCE	The maximum current drawn from the transducer should not exceed 25 ma to minimize self heating errors.		See Figure 2 & Reference 3
TIME CONSTANT (Note 5)	1063A 10 seconds, 1067A 1068A and 1710A 15 seconds	20 seconds	25 seconds
POWER CONSUMPTION (Note 6)	10 to 25 milliwatts typ	15 to 35 milliwatts typ	85 to 230 milliwatts typ See Figure 2
SELF HEATING ERROR	.004°C per milliwatt power dissipation typical with the transducer mounted in place and operated with standard or nominal supply voltages		
STABILITY	± 1°C over 90 days		± .25°C over 90 days
REFERENCE OUTPUT VOLTAGE		The +10 volt reference supply is available for use by auxiliary modules not drawing more than 15 ma Self heating error will be increased by supply load	

Note 1 Standard immersion length is 1 750 inches (44.4mm) as shown, longer lengths can be supplied.

Note 2. The maximum error incurred when the best straight line fit is used to approximate the transfer characteristic is as specified The straight line fit is between + 75 volts out and full scale output For current output models the fit is between 4 ma. and 20 ma.

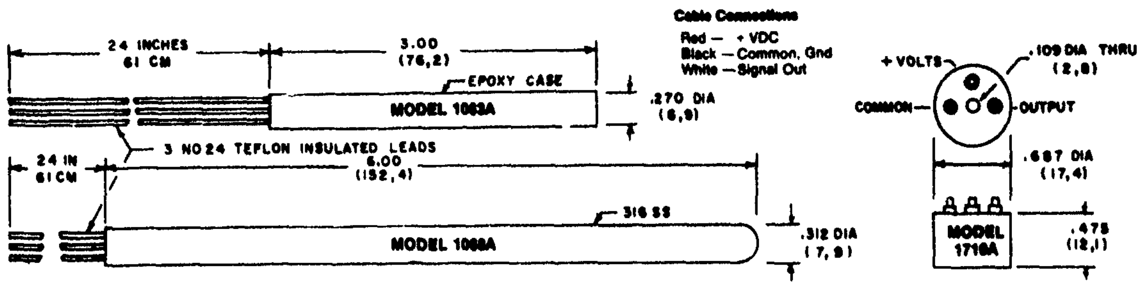
Note 3. The output signal departs from the specified linearity at levels of less than + 75 volts due to a drop in amplifier openloop gain as the amplifier approaches negative saturation

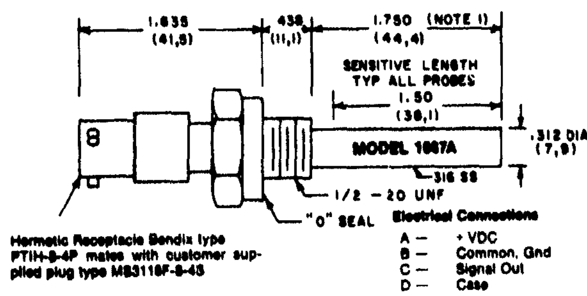
Note 4 The transducer should be operated with the minimum supply voltage consistant with anticipated voltage fluctuations for minimum self heating error

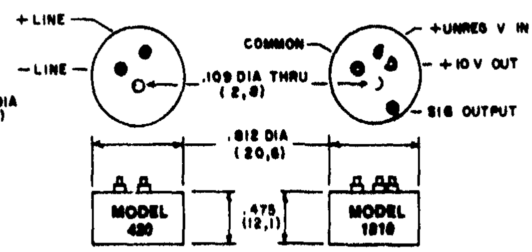
Note 5 Time Constant The time required for a 63% response to a step change from 24°C to an oil bath of #200 Dow Corning 1 5 CTSK at 76°C and flowing at 3FPS transverse to the sensing surface is less than the figure given The inservice response will depend upon how it is mounted and the environment in which it is used

Note 6 Power consumption depends upon the supply voltage, transducer load and output signal swing

Note 7 V out max for +5 volt units with sensitivities > 25 mv/°C is +3 volts







How to Specify

To order, specify the model number, required sensitivity using the Celsius scale of temperatures, full scale temperature in degrees Celsius together with sign, full scale output signal, and supply voltage.

1063A S050 P100 - 5 (15V)

- (15V) — Supply voltage. Example. +15 VDC
- 5 — Full scale output signal volts. Example: +5 VDC
- - — Dash
- P100 — Full scale temperature with sign, P for positive. Example. +100°C
- S050 — Sensitivity in millivolts per degree. Example: 50 mv/°C
- 1063A — Model designation. Ex: Model 1063A

420 S320 P40 - 20 (24V)

- (24V) — Nominal supply voltage Example: +24 VDC
- 20 — Full scale output current. Example: 20 milliamperes
- - — Dash
- P40 — Full scale temperature with sign, P for positive. Example: +40°C
- S320 — Sensitivity in microamperes per degree Celsius. Ex: 320 ua/°C
- 420 — Model designation Ex. Model 420

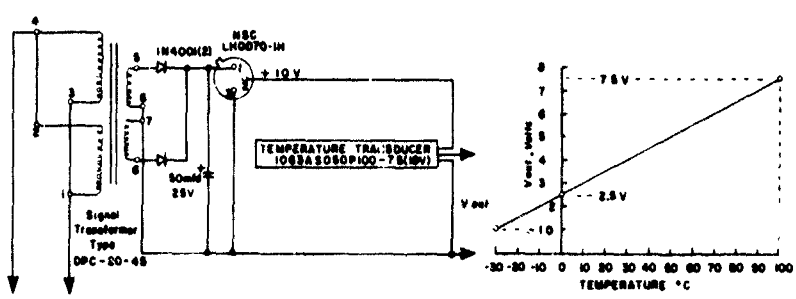


Figure 1 Electric thermometer using a Model 1063A transducer together with graph of the output signal.

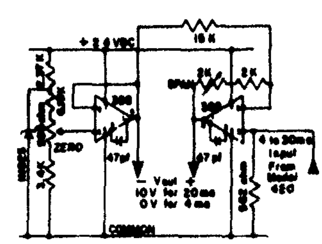


Figure 2 Process interface circuit for use with Model 420

RELCO PRODUCTS, INC.

5594 EAST JEFFERSON • DENVER, COLORADO 80237 • PHONE (303) 756-1143 JULY 1977

EXPANSION TANK SPECIFICATIONS

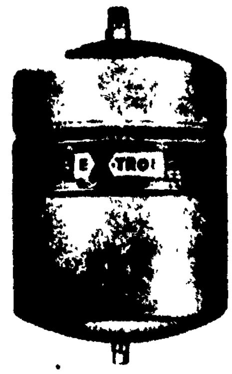
Atch 3

AMTROL INC.
1400 DIVISION ROAD • WEST WARWICK, R. I. 02893

BULLETIN 100-I
INSTALLATION INSTRUCTIONS
EX-TROL® EXPANSION TANKS
MARCH, 1974

This product represents the most recent development in providing for the expansion of water in a hydronic heating system.

The unique proven design of this tank, incorporating a flexible diaphragm that keeps the system water from contacting the (standard 12-lb.) tank charge, lets this considerably smaller size give more positive, permanent system protection.



No 15 EX-TROL ®

HOW IT WORKS

Heated water expands, and in a closed hot water heating system, provision must be made for this expansion. The flexible diaphragm in the EX-TROL® provides for water expansion without permitting absorption of the air cushion by the water.

TO INSTALL

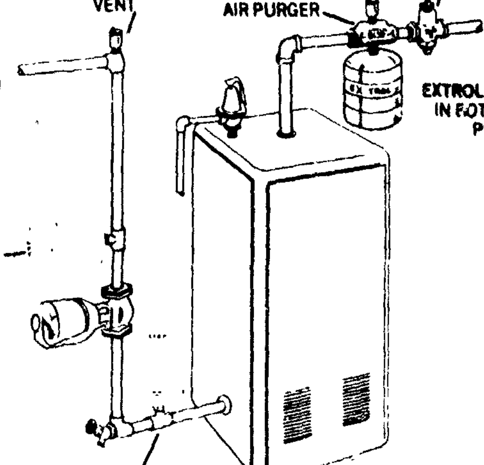
EX-TROL® may be installed into a tee or any other suitable tapping anywhere on a hot water heating system. It may be placed in a vertical or horizontal position. It may also be remotely located and piped to convenient point on the system.

An ideal EX-TROL® installation is to screw it into the bottom of an American Air Purger located on the main. This combination offers both a mounting tapping and continuous automatic air removal from the system.

After installing EX-TROL® on the system:

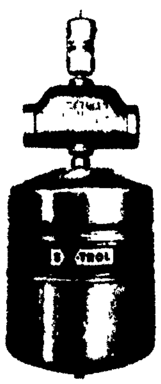
1. Fill system.
2. Vent air from system (for purging methods, refer to AMTROL data sheet on Purgers)
3. Bring system up to shut-off temperature.
4. If a smaller EX-TROL® is being used instead of that for which the system is sized, system water must be drawn from the boiler to maintain the proper system pressure. Generally a smaller than normal tank will cause a higher system pressure than is desirable.

Note: Never let air from EX-TROL® tank Air charge should always equal setting of reducing valve (12-lb. standard).



SYSTEM VENTING AND PURGING

After initial venting and purging of air from the system, more air will be released from the water as it is heated. Therefore, it is recommended that an American Air Purger and #700 Float Vent be installed on the main.



No 1500 EX-TROL ® Pkg.

If the system has multiple loops or zones, the supply water for all loops and zones must pass through the Air Purger for complete and continuous air removal. In case the piping arrangements does not permit the installation of a single Air Purger on the main, Air Purgers and #700 Float Vents snould be installed on each loop or zone. In this event, only one EX-TROL® is required for the system.

Even with American Air Purger and Float Vent installed on the main or mains, it is recommended the American #700 Float Vent be installed on each return at the elbow that drops to the circulator.

While seldom required, it is also recommended that manual (key or coin type) air vents be installed at high points on the radiation.

SERVICE HINTS

1 If system is shut down for long periods, or emptied for any reason, it may be necessary to repeat steps 2, 3 and 4 under INSTALLATION.

2. If the system pressure is too high:

a.) Check gauge calibration to make certain that the indicator needle has not slipped.

b) Check to see if EX-TROL® has lost its air charge.

Note: To get an accurate reading with any tire gauge when checking EX-TROL® air pressure, either:

1.) disconnect the EX-TROL® from the system or,

2.) draw off system water until boiler pressure reads zero.

c.) Check for faulty fill valve operation. First, close manual shut-off before the fill valve; then, draw system pressure down to 12 PSI (or other pre-set pressure) and observe system for pressure build-up several hours later

d.) Check for service water entering system from any other source of leak, such as tankless heater. Use same procedure as above after shutting off possible water source.

3. If pressure relief valve drips water:

a.) first, check system pressure. If too high, follow steps 2. b.), c.) and d.) above.

b) If pressure relief valve continues to drip water, even at reduced pressure, flush relief valve by quickly raising lever several times If drip continues, it may be necessary to replace relief valve.

c) If multiple EX-TROLS® are installed in the system, check pressure of each for possible air leaks Be sure red plastic air valve caps are on tight.

AMTROL INC.

1400 DIVISION ROAD • WEST WARWICK, R. I 02893

SOLAR HOUSE

HOMEOWNER'S MANUAL

(See Appendix E of this Report)

Atch 4

INSTRUMENTATION AND CONTROL

SYSTEM

Atch 5

INSTRUMENTATION AND CONTROL SYSTEM

The micro-computer used in the Solar Controller is a Zilog Z-80. Random Access Memory (RAM) is provided by a National INS 8154 RAM-I/O chip. This chip provides 128 bytes of memory and 16 I/O lines for controlling the home's heating system. Program storage is provided by a 2708 EPROM which has 1024 bytes of memory. The 16 I/O lines of the INS 8154 provide two ports - one for signal input and one for output. Port B uses eight I/O lines for output only. Port A uses the remaining eight lines as a bi-directional I/O bus. The output data to control the house operation is placed at Port A. Then one line of Port B, PB4, is pulsed high-low-high to latch the data into the 74LS374. (Refer to Figures 5-1 and 5-2.) Sensor information is input to Port A when the correct address for the channel desired is given to the H1818, AMUX; PB5 is brought low to start conversion from analog to digital, ADC, and enable the 81LS95 to latch the data to Port A. Prior to this, Port A has been reconditioned as an input port. After a time delay for conversion of data, the information is read into Port A and stored in memory. The system is totally memory mapped, that is, all devices including I/O are treated as memory. An ambiguous addressing scheme is used to select the desired peripheral device. The addressing is as follows:

0000H - 03FFH		PROM
0C00H - 0C7FH		RAM
0800H - 087FH		I/O

The flow diagrams for the computer software are contained in Figures 5-3, 5-4, and 5-5. The task scheduler initializes all control parameters and calls all subroutines needed for control of the heating system. These subroutines are called approximately every second which

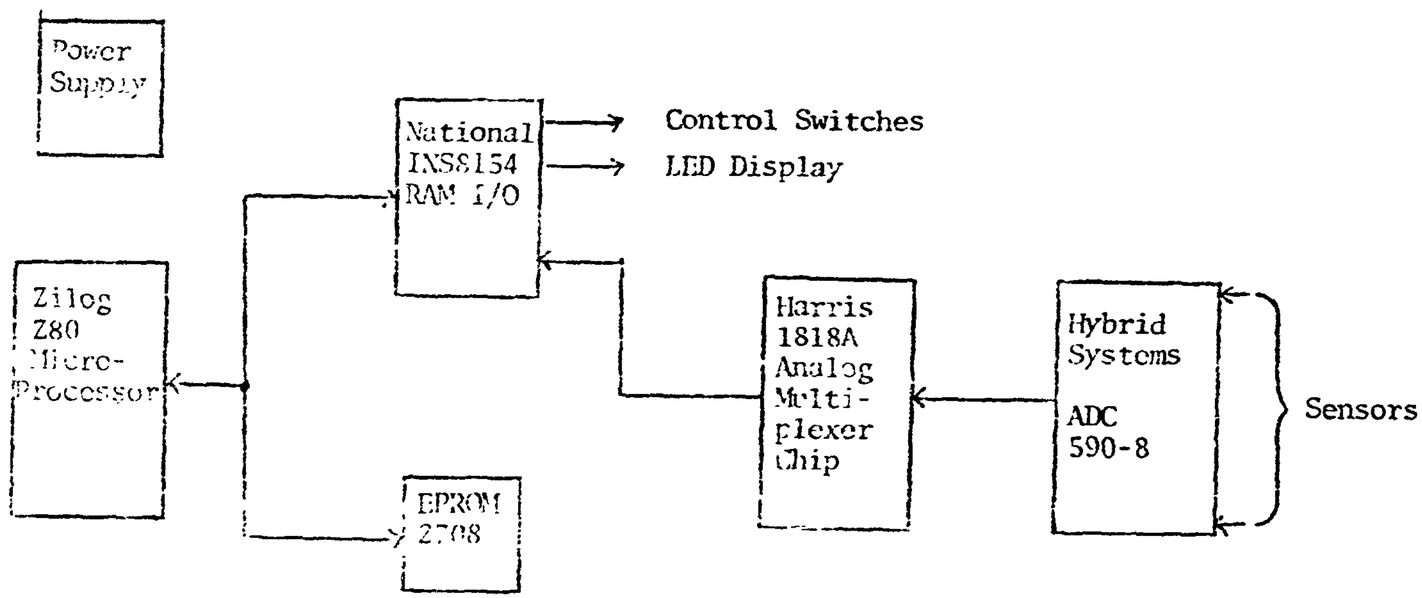
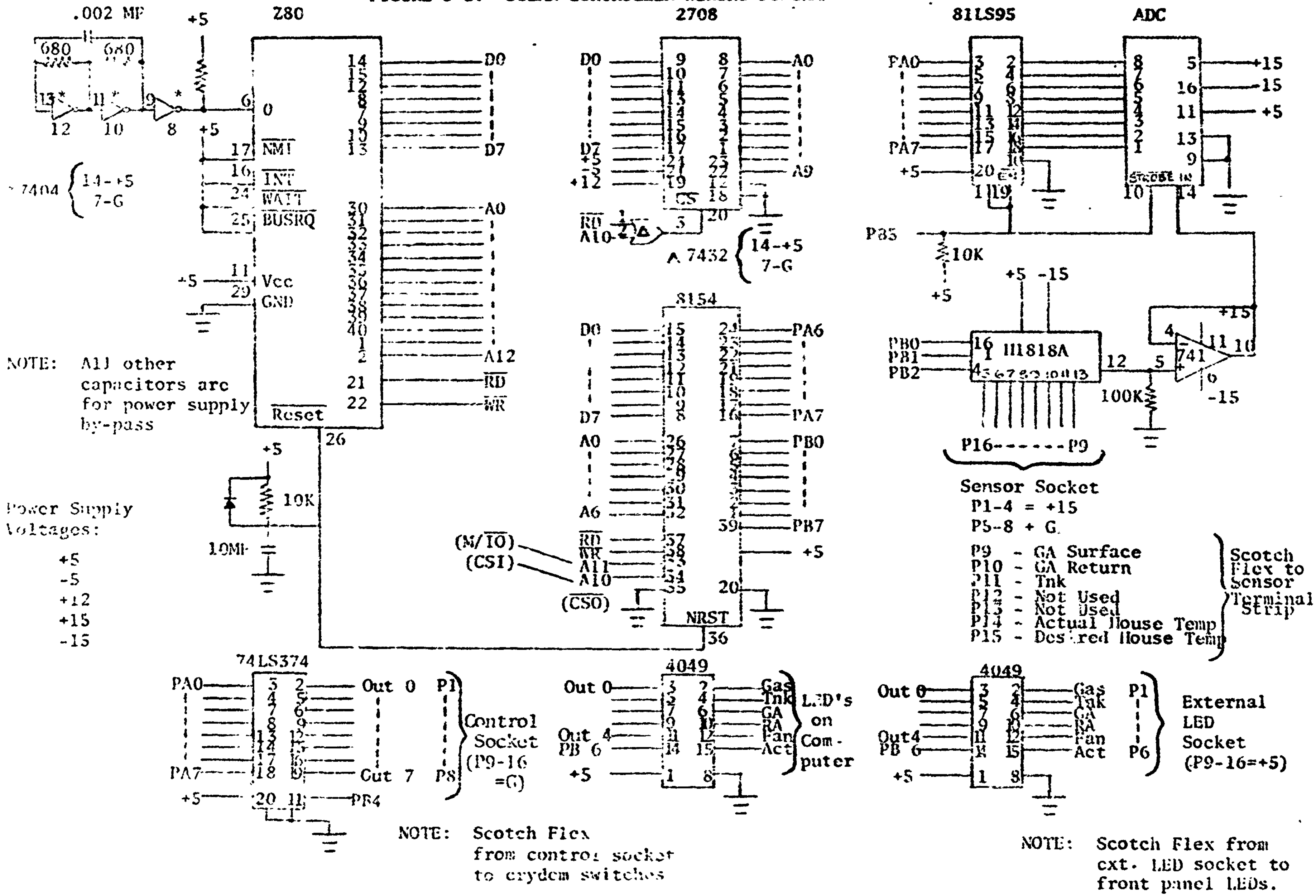


FIGURE 5-1. FUNCTIONAL BLOCK DIAGRAM OF SOLAR CONTROLLER

FIGURE 5-2. SOLAR CONTROLLER WIRING DIAGRAM



corresponds to the Activity Light Emitting Diode (LED) blinking on and off on the controller display panel.

The control program uses five temperature sensors to control the system. They are labeled as follows in the program.

T0 = Ground Array Collector Surface Temperature

T1 = Ground Array Collector Fluid Exit Temperature

T2 = Storage Tank Water Temperature

T5 = Actual Living Room Temperature

T6 = Requested Living Area Temperature (Thermostat Setting on the Controller)

The program is listed as Figure 5-6.

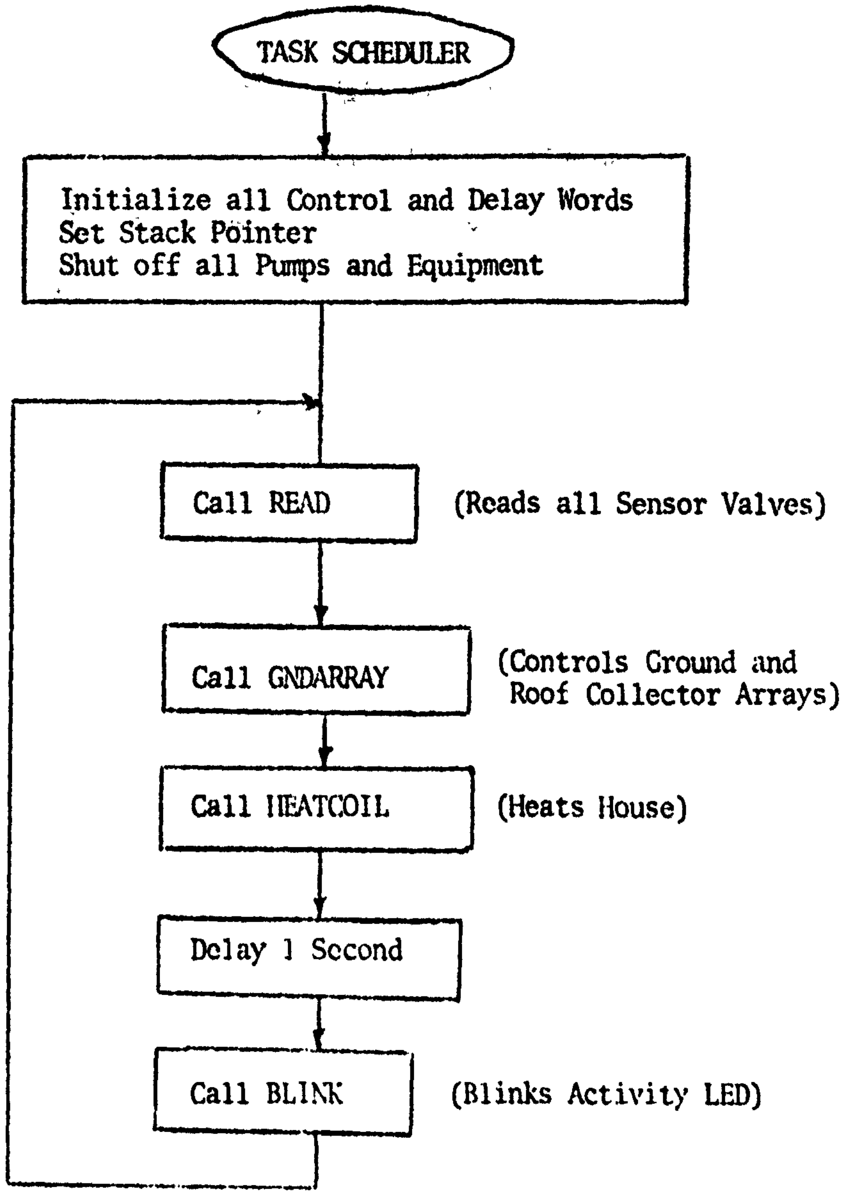


FIGURE 5-3. TASK SCHEDULER FLOW CHART

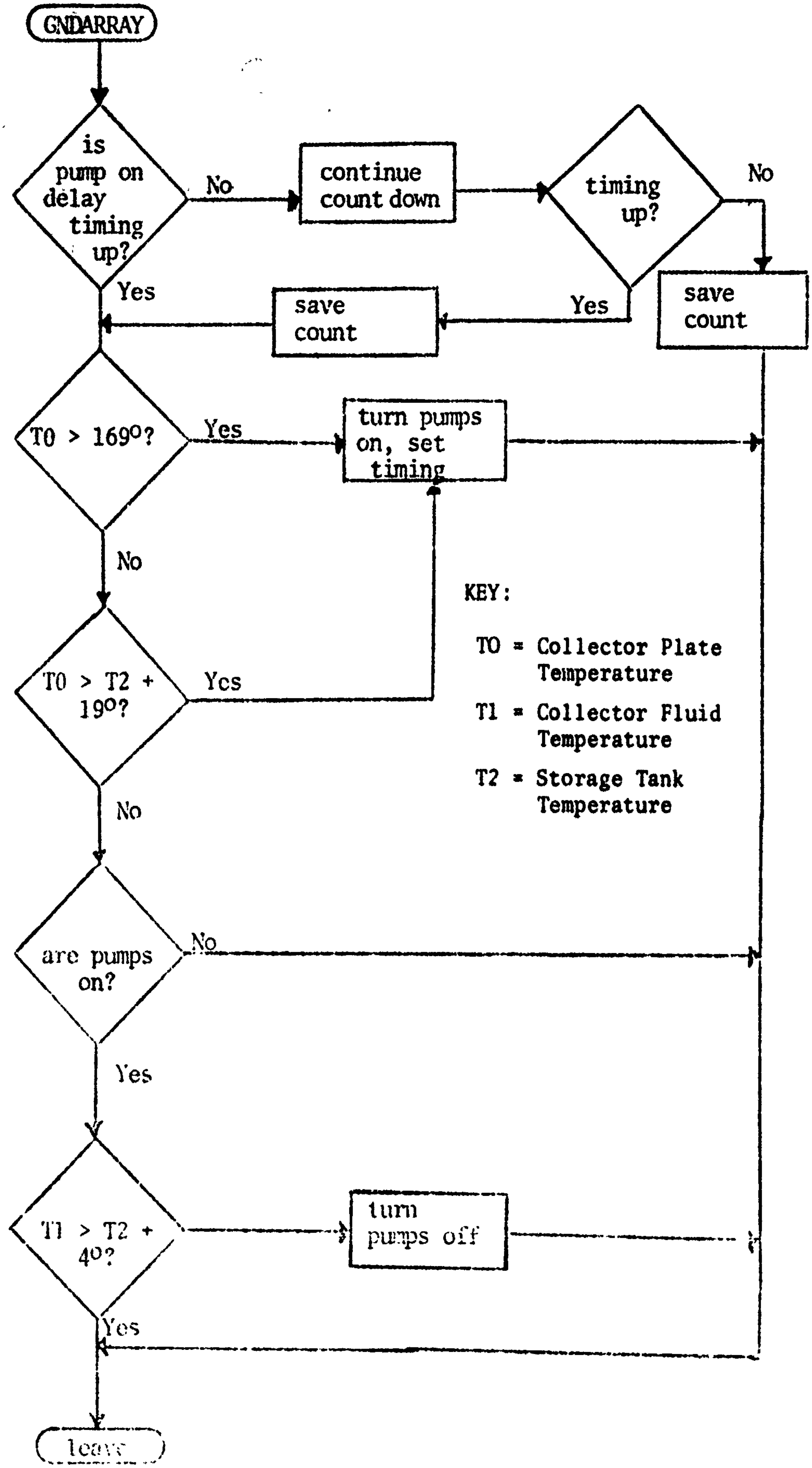


FIGURE 5-4. GROUND ARRAY CONTROL FLOW CHART

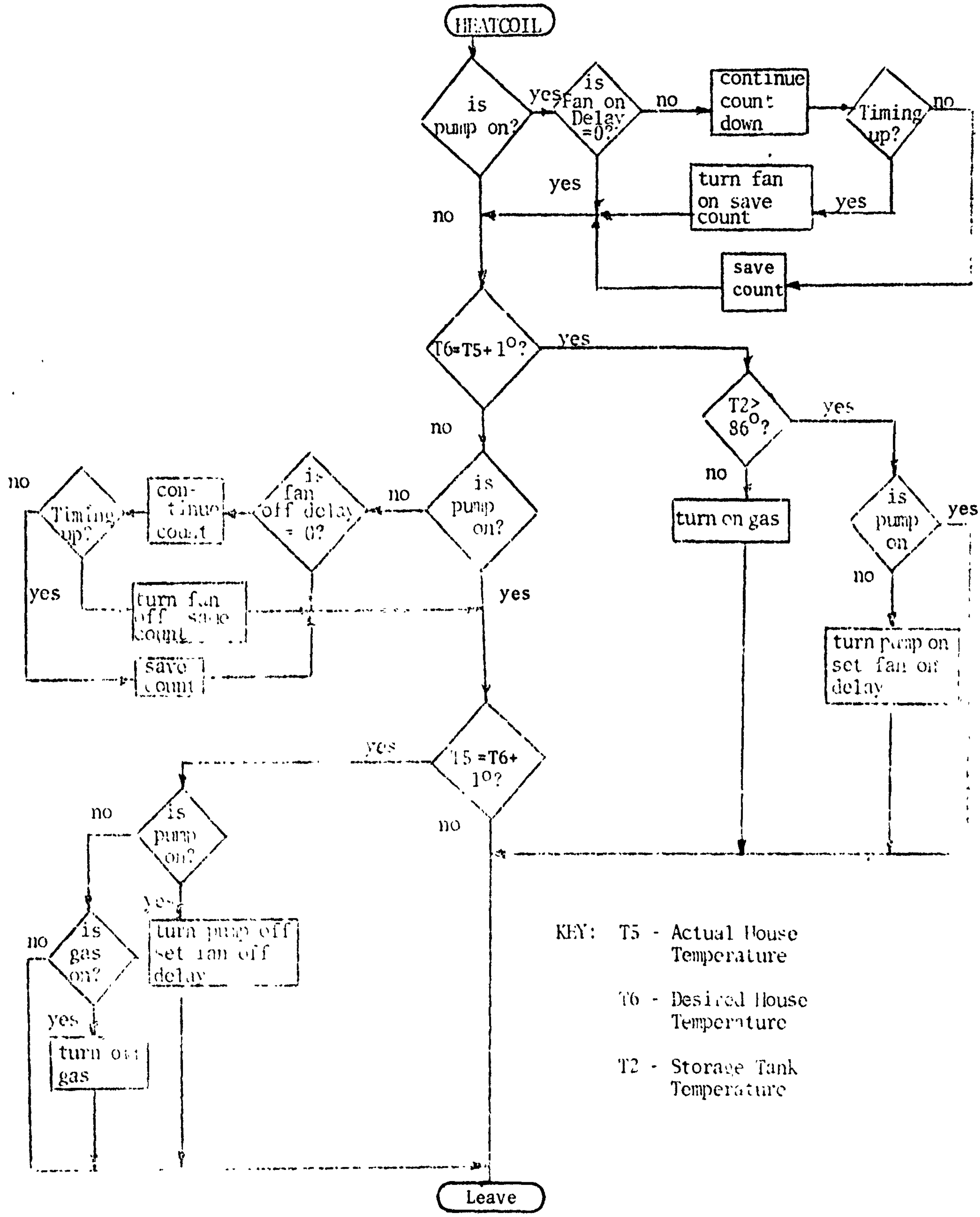


FIGURE 5-5. HEAT COIL CONTROL FLOW CHART

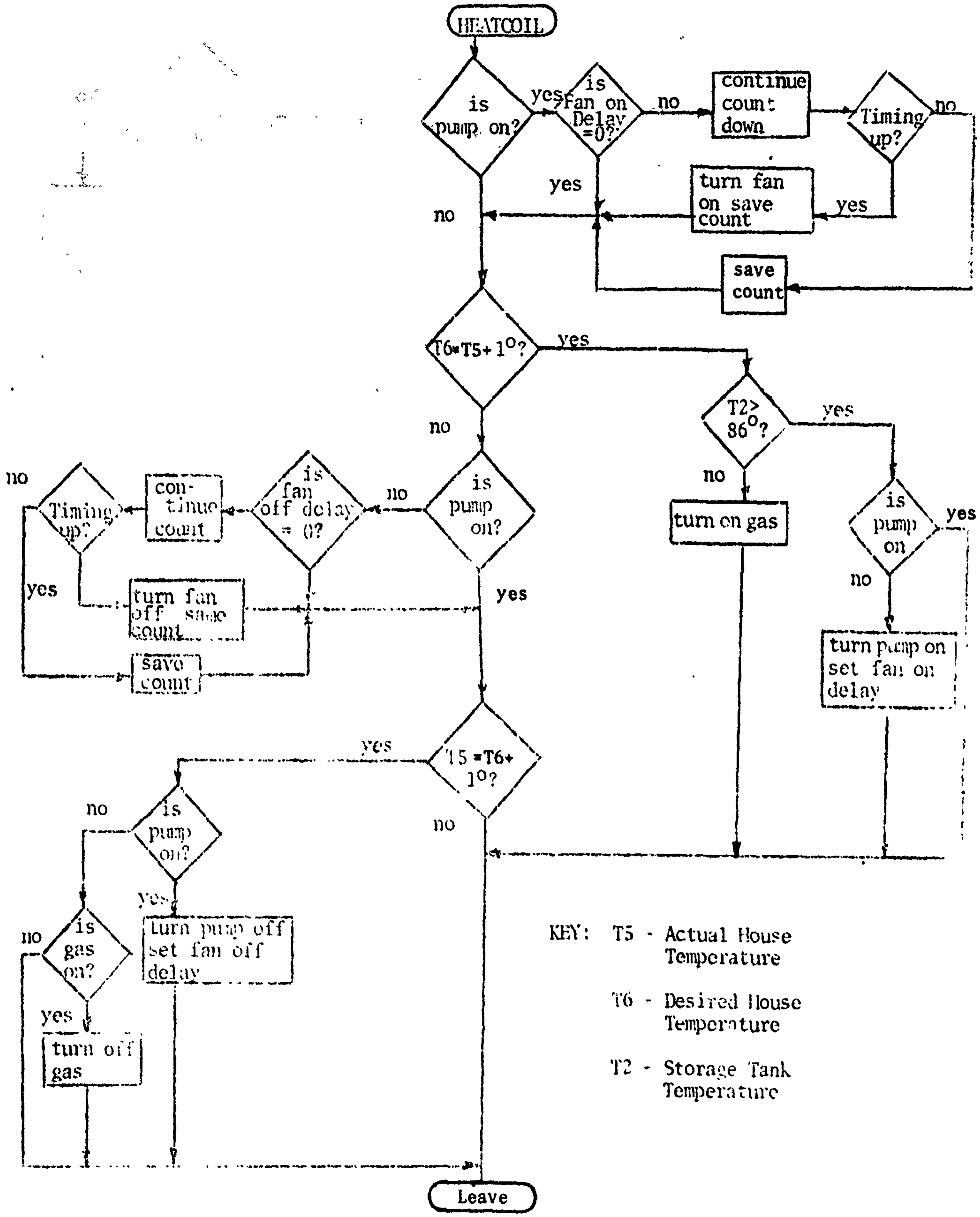


FIGURE 5-5. HEAT COIL CONTROL FLOW CHART

```
        ADI     19          ;A=T2+19
        LXI     H,T0        ;GET SURFACE TEMP
        CMP     M           ;T0>T2+19?
        JNC     ONE         ;NO CHECK WATER TEMP
        LDA     PUMP        ;YES-GET CONTROL WORD
        ORI     0CH         ;OUTPUT PUMPS ON CONTROL WORD
        CALL    CONTROL     ;TURN PUMPS ON
        STA     PUMP        ;SAVE CONTROL WORD
        MVI     A,5C        ;SET TIMING
        STA     GADLA       ;SAVE CONTROL WORD
        RET
ONE:    PUSH    PSW         ;CHECK TO SEE IF PUMP ON
        LDA     PUMP        ;GET CONTROL WORD
        ANI     4           ;IS PUMP ON?
        JZ      GEXIT       ;NO LEAVE
        POP     PSW         ;YES CHECK OTHER TEMPS
TWO:    LDA     T2          ;GET TANK TEMP
        ADI     4           ;A=T2+4
        LXI     H,T1        ;GET EXIT TEMP(T1)
        CMP     M           ;T1>T2+4?
        JNC     THREE       ;NO TURN OFF PUMPS
        RET                 ;YES RETURN
THREE:  LDA     PUMP        ;GET CONTROL WORD
        ANI     0F3H        ;OUTPUT PUMPS OFF WORD
        CALL    CONTROL     ;TURN PUMPS OFF
        STA     PUMP        ;SAVE CONTROL WORD
        RET
GEXIT:  POP     PSW         ;LEAVE
        RET
;
;HEATCOIL CHECKS TO SEE IF HEAT IS REQUIRED AND IF SO DECIDES
;WHEATHER TO HEAT BY SOLAR OR GAS
;
HEATCOIL: LDA   PUMP        ;SEE IF PUMP IS ON IF SO SEE IF FAN
        ANI     2           ;SHOULD BE TURNED ON.
        CNZ     FANON       ;
        LDA     T5          ;GET LIVING AREA TEMP
        ADI     1           ;A=T5+1
        LXI     H,T6        ;GET LIVING AREA REQ TEMP
        CMP     M           ;T6>T5+1?
        JNC     WARM        ;NO CHECK ON THE HEATING
COLD:   CALL    SORGAS      ;YES THEN HEAT BY SOLAR OR GAS
        RET
WARM:   CALL    SH          ;CHECK TO STILL HEATING
        RET
SORGAS: LDA     T2          ;GET TANK TEMP
        CPI     66          ;T2>66?
        JNC     TANKH       ;YES HEAT BY TANK
        CALL    GAS         ;NO HEAT BY GAS
        RET
TANKH:  CALL    PUMPON      ;ROUTINE TO TURN PUMP ON
        RET
GAS:    LDA     PUMP        ;GET CONTROL WORD
        ORI     1           ;OUTPUT GAS ON WORD
        ANI     0FH         ;MAKE SURE TO TURN OFF TNK&FAN
        CALL    CONTROL     ;TURN GAS ON
        STA     PUMP        ;SAVE CONTROL WORD
        RET
PUMPON: LDA     PUMP        ;GET CONTROL WORD
        ANI     2           ;IS PUMP ON?
        JNZ     PISON       ;YES RETURN
        LDA     PUMP        ;NO GET CONTROL WORD
        ORI     2           ;OUTPUT PUMP ON WORD
        CALL    CONTROL     ;TURN PUMP ON
        STA     PUMP        ;SAVE CONTROL WORD
        MVI     A,5C        ;SET TIMING FOR FAN ON
        STA     FDLA        ;STORE IN FAN ON DELAY
PISON:  RET
FANON:  LDA     FDLA        ;GET CONTROL WORD
        ANA     A           ;SET FLAGS
        JZ      EXIT        ;IF FAN ON LEAVE
```

FIGURE 5-6 (cont)

```
          DCR      A            ;START COUNTING DOWN
          JNZ      NOYET        ;IF TIME NOT UP LEAVE
          STA      FOLA         ;SAVE CONTROL WORD
          LDA      FUMP         ;GET CONTROL WORD
          ORI      C1CH         ;OUTPUT FAN ON WORD
          CALL     CONTROL      ;TURN FAN ON
          STA      FUMP         ;SAVE CONTROL WORD
          RET
NOYET:    STA      FOLA         ;SAVE COUNT
EXIT:     RET
SH:       CALL     FCFF         ;SEE IF FAN SHOULD BE TURNED OFF
          LDA      T6           ;GET REQ TEMP
          ADI      1            ;A=T6+1
          LXI      H,T5         ;GET LIVING AREA TEMP
          CMP      M            ;T5>T6+1?
          RNC                   ;NO STILL HEATING
          CALL     FOFF         ;YES TURN PUMP OR GAS OFF
          RET
PCFF:     LDA      FUMP         ;GET CONTROL WORD
          ANI      2            ;IS PUMP ON?
          JZ       GASOFF       ;NO CHECK GAS
          LDA      FUMP         ;GET CONTROL WORD
          ANI      CFCH         ;OUTPUT PUMP OFF WORD
          CALL     CONTROL      ;TURN PUMP OFF
          STA      FUMP         ;SAVE CONTROL WORD
          MVI      A,50         ;SET FAN OFF TIMING
          STA      FOFD         ;STORE IT IN FAN OFF DELAY
          RET
GASOFF:   LDA      FUMP         ;GET CONTROL WORD
          ANI      1            ;IS GAS ON?
          JZ       LEV          ;NO RETURN
          LDA      FUMP         ;GET CONTROL WORD
          ANI      CFEH         ;OUTPUT GAS OFF WORD
          CALL     CONTROL      ;TURN GAS OFF
          STA      FUMP         ;SAVE CONTROL WORD
LEV:      RET
FOFF:     LDA      FUMP         ;GET CONTROL WORD
          ANI      2            ;SEE IF PUMP IS ON IF SO WE LEAVE
          RNZ                   ;THE FAN ALONE
          LDA      FOFD         ;GET THE DELAY WORD
          ANA      A            ;SET FLAGS
          JZ       FEXIT        ;IF FAN OFF LEAVE
          DCR      A            ;START COUNTING DOWN
          JNZ      WAIT         ;IF NOT TIME LEAVE
          STA      FOFD         ;SAVE CONTROL WORD
          LDA      FUMP         ;GET CONTROL WORD
          ANI      CFFH         ;OUTPUT FAN OFF WORD
          CALL     CONTROL      ;TURN FAN OFF
          STA      FUMP         ;SAVE CONTROL WORD
          RET
WAIT:     STA      FOFD         ;SAVE COUNT
FEXIT:    RET
;
;CONTROL OUTPUTS CONTENTS OF ACC TO
;CONTROL PORT--ACC UNAFFECTED
;
CONTROL:  PUSH     PSW          ;SAVE VALUE TO BE OUTPUT
          MVI      A,7FH        ;SET PORT B TO OUTPUT
          STA      C410H        ;MAKE SURE BUFFER IS OFF
          STA      C423H        ;SET PORT B TO OUTPUT
          MVI      A,0FFH
          STA      C422H        ;SET PORT A TO OUTPUT
          POP      PSW          ;GET VALUE BACK
          STA      C420H        ;WRITE IT OUT TO THE LATCH
          STA      C40CH        ;STROBE THE LATCH
          STA      C41CH        ;
          RET
;
;D8MS-DELAYS 8 MILLISECONDS-B AND C AFFECTED
;
D8MS:     MVI      C,10H        ;WAIT FOR 8 MS
```

FIGURE 5-6 (Cont)

```
DIMS:   DCR     C               ;ONLY EC PAIR AFFECTED
        JNZ     DIMS            ;
        DCR     E               ;
        JNZ     DIMS            ;
        RET
        ;
        ;BLINK-FLASHES ACTIVITY LED EACH TIME CALLED
        ;
BLINK:  PUSH    PSW             ;SAVE A
        LDA     C421H           ;GET PORT 3 DATA
        XRI     40H             ;COMPLEMENT BIT 6
        STA     C421H           ;COMPLEMENT LED
        POP     PSW             ;
        RET
        ;
        ;SENSE-READ SW INPUT,SETS ZERO FLAG
        ;
SENSE:  LDA     C40FH           ;GET BIT 7 ONLY
        ORA     A               ;SET FLAG
        RET
        ;
        ;THIS ROUTINE READS ALL OF THE SENSORS AND STORES
        ;THEM IN RAM STARTING AT 0C00H-0C07H. IN THE
        ;PROPER ORDER-NO REG ARE AFFECTED
        ;
READ:   PUSH    PSW             ;SAVE EVERYTING
        PUSH    B               ;
        PUSH    H               ;
        LXI     H,0C07H         ;READ ALL SENSORS AND STORE
        XRA     A               ;CLEAR A
        STA     C422H           ;SET PORT A TO INPUT
        MVI     A,7FH           ;SET PORT 3 TO OUTPUT
        STA     C423H           ;EXCEPT PB7
READ1:  LDA     C421H           ;GET PORT B STATUS BITS
        ANI     0F8H            ;SAVE EVERYTHING EXCEPT
        ORA     L               ;LOW 3 BITS, MERGE CHANNEL
        ORI     30H             ;NUMBER,MAKE SURE THE LATCH
        STA     C421H           ;IS RESET AND BUFFER IS OFF
        MVI     B,01            ;WAIT 1 MS FOR 741
        CALL    DIMS            ;TO SETTLE
        STA     C20CH           ;STROBE PB5
        MVI     B,01            ;WAIT 1 MS FOR ADC
        CALL    DIMS            ;TO GET DONE
        LDA     C42CH           ;GET DATA
        STA     C410H           ;RESET STROBE AND BUFFER
        MOV     M,A             ;STORE THE RESULT IN RAM
        DCR     L               ;GO TO NEXT CHANNEL
        JP      READ1           ;NOT DONE YET
        POP     H               ;ALL DONE LETS LEAVE
        POP     B               ;
        POP     PSW             ;
        RET
        END
```

FIGURE 5-6 (cont)

APPENDIX E

SOLAR HOUSE

HOMEOWNER'S MANUAL

TABLE OF CONTENTS

1.0 History and Introduction

The solar system installed in your home was constructed in 1975 as part of an official Air Force research project. It is the first Air Force home to be equipped with a solar system. The project's goal was to investigate the feasibility of using solar energy to provide a significant portion of the space heating energy requirements for a typical MFH unit. The research project was terminated in 1979. It was demonstrated that the solar system would provide approximately 60 percent of the heating requirements during a typical winter season. Stated simply, your home will consume 60 percent less natural gas than other identical homes at the Academy. Although we feel that the solar energy system will be relatively trouble free, you can help to insure that it does function properly. In a very real sense, therefore, you have a unique opportunity to contribute to the Air Force's and the nation's energy goals.

This manual explains in lay terms the operation of the solar system that heats your house. The solar collector panels are divided between the roof array and the ground array in the back yard. All pumps and associated control equipment are located in an equipment room on the northwest end of the basement. (For those who don't possess a good sense of direction, it's located to the left at the bottom of the basement stairs.) You are not expected to become an expert on solar heating systems, but as the occupant you should be aware of the topics discussed in this manual.

2.0 Do's and Don'ts

There is only one "DON'T" associated with the solar home.

> DO NOT SET THE CONVENTIONAL WALL-MOUNTED THERMOSTAT IN THE LIVING ROOM AT A HIGHER TEMPERATURE SETTING THAN THE SOLAR CONTROLLER THERMOSTAT IN THE BASEMENT.

SEE SECTION 4.0 OF THIS MANUAL FOR FURTHER INFORMATION REGARDING THIS RULE.

3.0 General Overview of House Operation

The fundamental operation of the solar system involves collection of the sun's energy as heat. During sunny periods (even during cold weather) a water/antifreeze mixture is circulated by pumps through the solar collector panels. This collector fluid will become very hot. The two pumps used to circulate the fluid through the ground and roof arrays are labeled clearly in the basement. The hot collector fluid from both arrays then passes through submerged heat exchangers in an underground, concrete storage tank which is filled with water (no antifreeze is in the storage tank water). This underground tank is near the northwest corner of the house.

Within the tank, the heat is transferred from the collector fluid to the storage water by the submerged heat exchangers. When the house requires heat the hot storage tank water is pumped (by a separate pump) into the house and thorugh a water-to-air exchanger near the gas furnace. Air is then blown across this heat exchanger by the furnace fan. The air, heated in this manner, is distributed into the house by the normal furnace duct system. If the temperature of the solar heated water in the storage tank is <u>not</u> high enough to heat the home, the gas furnace will come on as a backup. (No solar system, including the one installed in your home, is designed to supply 100 percent of the energy required to heat a house.)

4.0 Solar Controller Operation

The single most important item in the solar heating system is the black box located on the wall of the equipment room. (Figure 1.) This

box contains a "mini-computer" which controls the entire heating system (i.e., the solar equipment and the auxiliary gas furnace). Figure 1 shows the display panel of the solar controller.

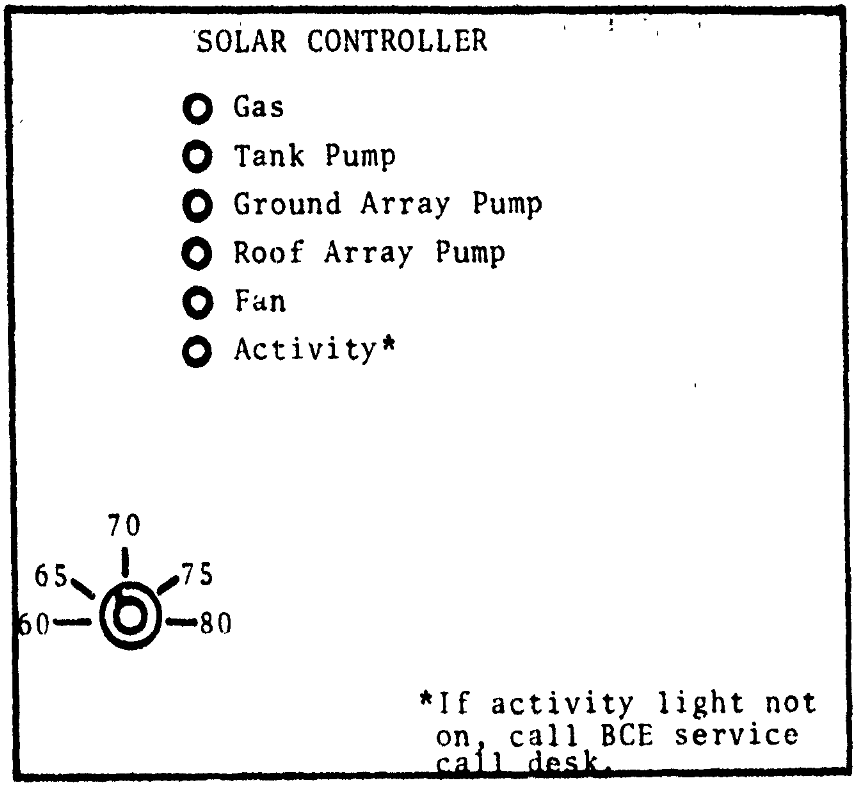


Figure 1. The "Mini-Computer" Solar Controller

If the solar controller malfunctions, the house will probably not be heated by solar energy. The only real operation you can do with the controller is to adjust the thermostat. Base Civil Engineering has requested that all thermostats be set at 68^{o}F and this also applies to the Solar Controller. If you notice that you have to turn this thermostat up to an unusually high setting to remain comfortable, call Civil Engineering and have them check it. You will notice that there is also a normal, wall-mounted thermostat upstairs in the living area. This

thermostat controls only the back-up gas furnace. This thermostat should always be set lower than the Solar Controller thermostat, preferably at around 55-60°F. If the Solar Controller malfunctions, however, the upstairs thermostat can then be set to the desired temperature and the house will be heated solely by the gas furnace just like a normal home. If you are heating the home in this mode, Civil Engineering should be notified. The only other aspect of the Solar Controller you should be concerned with is the display lights.

The display lights on the Solar Controller are fairly self-explanatory, but the following comments should be helpful in understanding them further. The ACTIVITY light should blink all the time, night and day. If this is not the case, call the Civil Engineering Service Desk.

If the GAS light is on, this indicates that the controller is directing that the home be heated by the gas furnace. Naturally, if this light is on then the gas furnace should be on also. If the furnace either isn't on or is on during a period when it shouldn't be (e.g., when the home doesn't require heat) then the system has malfunctioned and Civil Engineering should be notified.

The TANK PUMP light comes on when the controller is directing that the home be heated by the solar heated water in the storage tank. The storage tank pump should be running if this light is on. If the pump is not running when the light is on, or conversely, runs when the light is not on, then a malfunction has occurred. Also, if this pump runs when the home does not require heat, it is malfunctioning. In any case, Civil Engineering should be notified.

The FAN light should come on and go off 40 seconds after the TANK PUMP light comes on or goes off. It simply indicates that the computer

is controlling the furnace fan. (You will remember that the furnace fan must be on in order to transfer the heat from the hot storage tank water in the furnace heat exchanger to the air which heats your home.) Should this malfunction, either the fan will not come on or it will stay on. In either case, call Civil Engineering. Note that the Solar Controller does not turn the fan on in conjunction with the gas furnace but only with the tank pump.

The GROUND ARRAY and ROOF ARRAY lights come on simultaneously when the computer has instructed the ground and roof array collector pumps to start. This should occur only during sunny periods. The lights and respective pumps should go off in the late afternoon or during cloudy periods. If you notice any unusual occurrence, like the pumps on and the associated lights not on, or vice versa, the lights on and the pumps not on, a malfunction has occurred. Under no circumstances should these lights or the ground and roof array pumps be on at night. Civil Engineering should be notified if these malfunctions occur.

This concludes most aspects of the Solar Controller operation, but if something suspicious happens, you know what to do -- call Civil Engineering!

5.0 Solar Controller Summary

Please refer to the attached diagrams for a concise visual description of the various operational modes which the system can display during normal operation. Other operational modes are possible, but those shown are most typical and should aid your understanding of the system.

● Display Light On

○ Display Light Off

MODE 1

SOLAR CONTROLLER

○ Gas

○ Tank Pump

○ Ground Array

○ Roof Array

○ Fan

○ Activity (Blinking)

Systems are shut down; sun is not shining therefore collector arrays are not operating; house does not require heat, therefore storage tank pump or gas furnace is not operating.

● Display Light On

○ Display Light Off

MODE 2

SOLAR CONTROLLER
- ○ Gas
- ○ Tank Pump
- ● Ground Array
- ● Roof Array
- ○ Fan
- ○ Activity (Blinking)

Both collector array pumps on. Sun is shining and solar energy is being collected and transferred to storage tank water.

MODE 3

SOLAR CONTROLLER
- ○ Gas
- ● Tank Pump
- ○ Ground Array
- ○ Roof Array
- ● Fan
- ○ Activity (Blinking)

Storage tank pump and fan are on. Hot storage tank water is being pumped through the furnace heat exchanger; therefore the home is being heated by solar energy. Sun is not shining, however, and collectors are not operating.

MODE 4

SOLAR CONTROLLER
- ○ Gas
- ● Tank Pump
- ● Ground Array
- ● Roof Array
- ● Fan
- ○ Activity (Blinking)

Mode 2 and Mode 3 comments apply.

MODE 5

SOLAR CONTROLLER
- ● Gas
- ○ Tank Pump
- ● Ground Array
- ● Roof Array
- ○ Fan
- ○ Activity (Blinking)

Mode 2 comments apply. The home is being heated by the gas furnace since the temperature of the storage tank water is not high enough to provide the necessary energy.

● Display Light On
○ Display Light Off

MODE 6

SOLAR COLLECTOR

● Gas

○ Tank Pump

○ Ground Array

○ Roof Array

○ Fan

○ Activity
(Blinking)

House requires heat which is being provided by the gas furnace. The temperature of the solar heated storage tank water is not high enough to provide the necessary energy. Sun is not shining, therefore, collector arrays are not operating.

6.0 Base Civil Engineering Periodic Maintenance

Civil Engineering maintenance personnel will perform preventive maintenance on the solar system from time to time. These checks are primarily to determine the degree of freeze protection in the collector fluid; visits will normally be made in August and January. Civil Engineering will, of course, contact you prior to scheduling these checks.

7.0 Collector Fluid Leak/Glass Breakage

If you should happen to notice a fluid leak or a broken glass cover in either collector array, Civil Engineering should be notified. A leak in the roof array collectors would probably be evidenced by appearance of green fluid in the gutter downspouts.